

(12) **United States Patent**  
**Burgess et al.**

(10) **Patent No.:** **US 9,302,770 B2**  
(45) **Date of Patent:** **\*Apr. 5, 2016**

(54) **PAYLOAD-RELEASE DEVICE AND OPERATION THEREOF**

(71) Applicant: **Google Inc.**, Mountain View, CA (US)

(72) Inventors: **James Ryan Burgess**, Redwood City, CA (US); **Joanna Cohen**, Mountain View, CA (US)

(73) Assignee: **Google Inc.**, Mountain View, CA (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/875,362**

(22) Filed: **Oct. 5, 2015**

(65) **Prior Publication Data**

US 2016/0059963 A1 Mar. 3, 2016

**Related U.S. Application Data**

(63) Continuation of application No. 14/584,181, filed on Dec. 29, 2014, now Pat. No. 9,174,733.

(60) Provisional application No. 62/043,396, filed on Aug. 28, 2014.

(51) **Int. Cl.**

**B64D 1/12** (2006.01)

**B64C 39/02** (2006.01)

**B64D 9/00** (2006.01)

(52) **U.S. Cl.**

CPC ..... **B64D 1/12** (2013.01); **B64C 39/024** (2013.01); **B64D 9/00** (2013.01); **B64C 2201/128** (2013.01)

(58) **Field of Classification Search**

CPC ..... B64D 1/12; B64D 9/00; B64C 39/024; B64C 2201/128

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0091261 A1\* 4/2012 Lee ..... B64B 1/50 244/33

OTHER PUBLICATIONS

Notice of Allowance for U.S. Appl. No. 14/584,181, mailed Jul. 2, 2015, 20 pages.

\* cited by examiner

*Primary Examiner* — Mussa A Shaawat

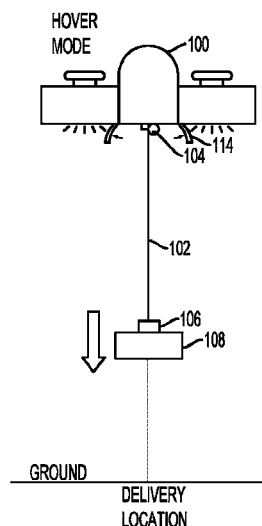
*Assistant Examiner* — Yuen Wong

(74) *Attorney, Agent, or Firm* — McDonnell Boehnen Hulbert & Berghoff

(57) **ABSTRACT**

An unmanned aerial vehicle (UAV) is disclosed that includes a retractable payload delivery system. The payload delivery system can lower a payload to the ground using a delivery device that secures the payload during descent and releases the payload upon reaching the ground. The delivery device can include a channel in which a payload mount attachment for a payload can be inserted. The payload mount attachment can include an aperture for receiving a retaining rod to secure the attachment, and thus the payload, to the delivery device. The retaining rod can assume either an engaged position, in which a portion of the retaining rod engages the payload mount attachment while the payload mount attachment is inserted in the channel, or a disengaged position, in which the retaining rod does not engage the payload mount attachment.

**19 Claims, 15 Drawing Sheets**



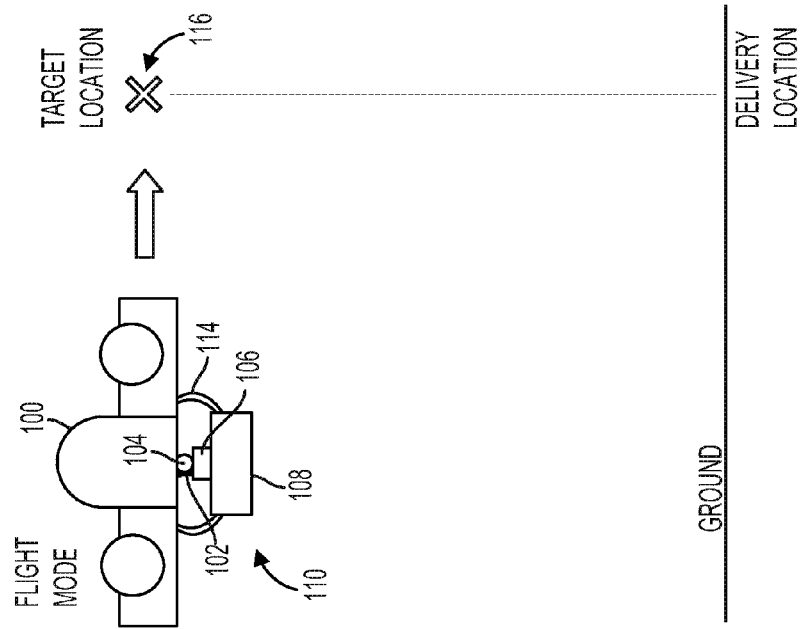


FIG. 1A

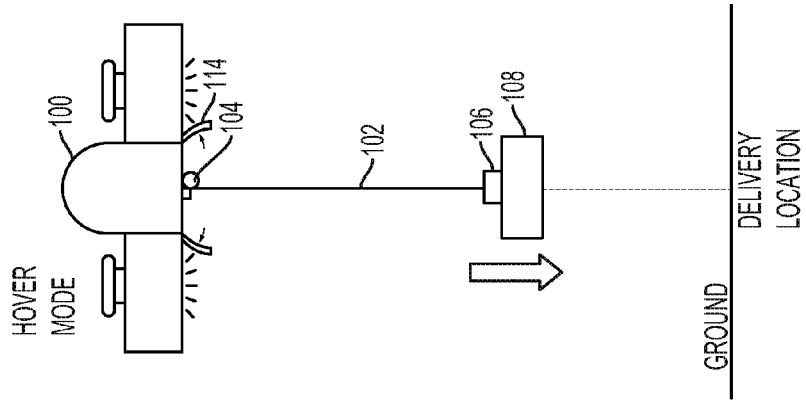


FIG. 1B

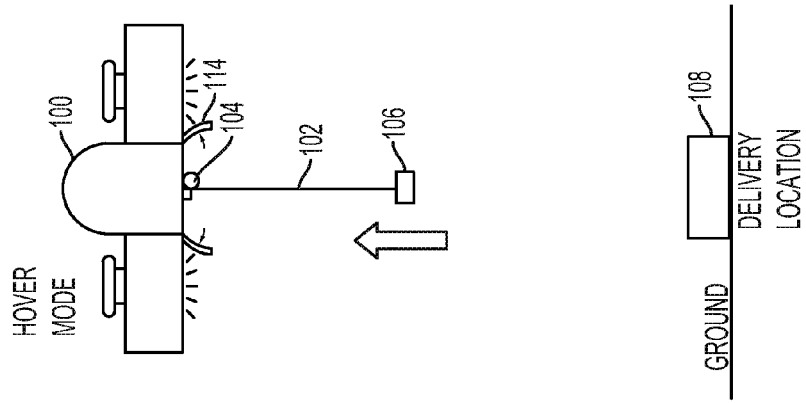


FIG. 1C

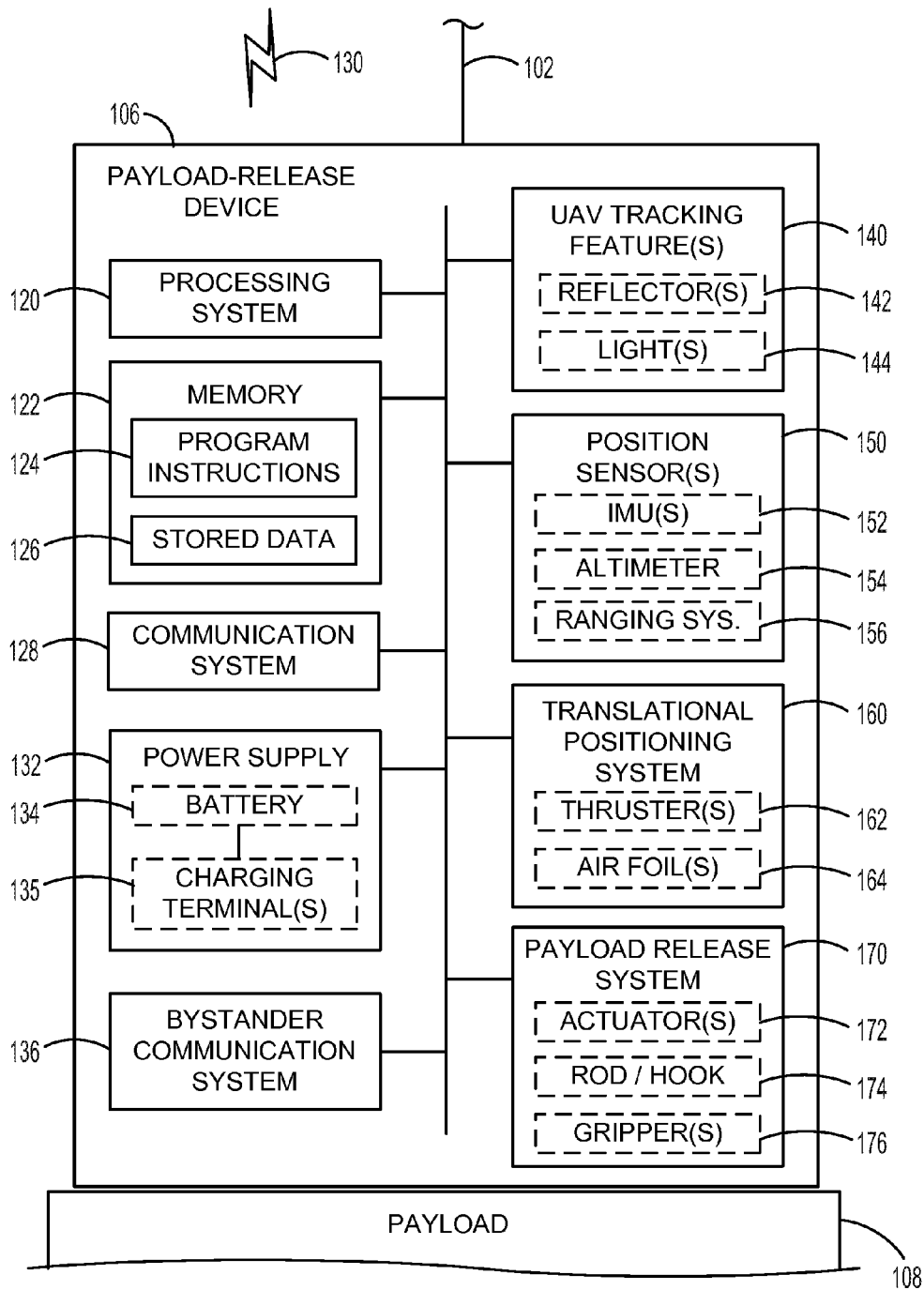


FIG. 1D

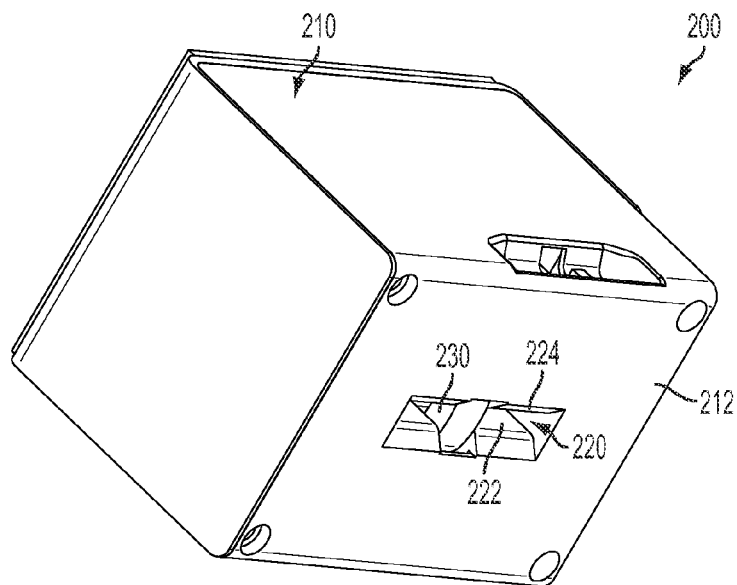


FIG. 2A

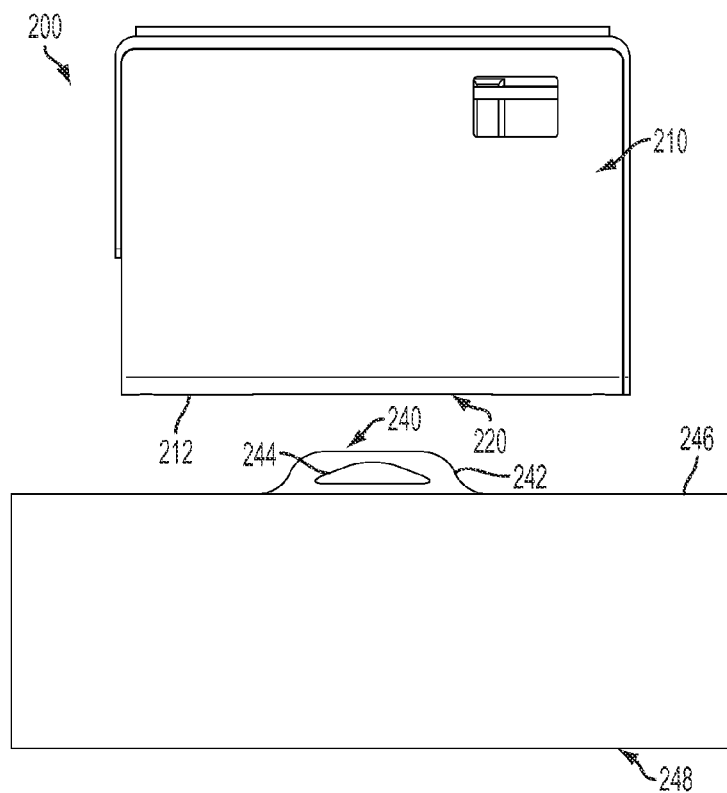


FIG. 2B

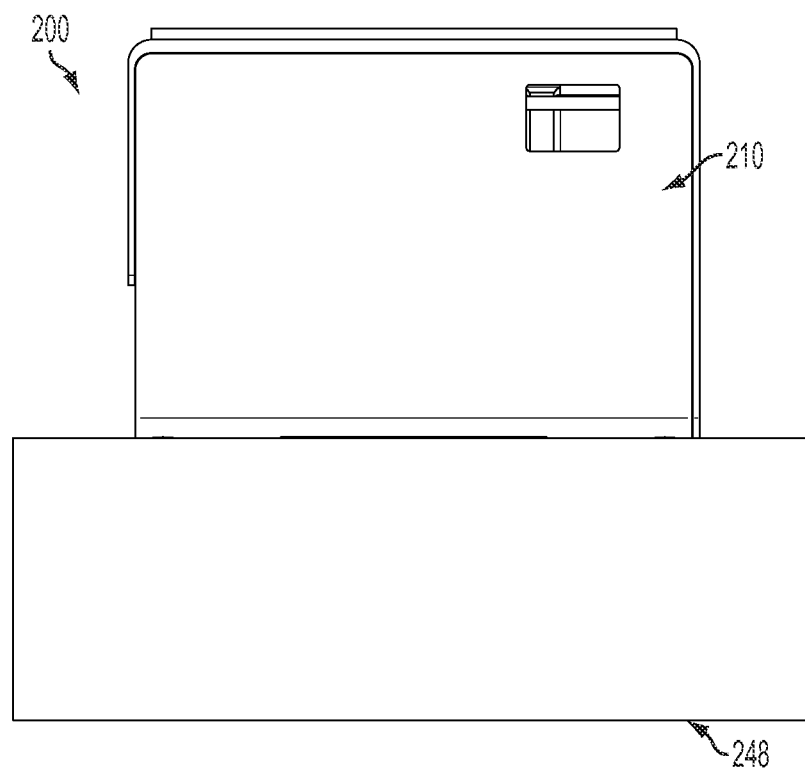


FIG. 2C

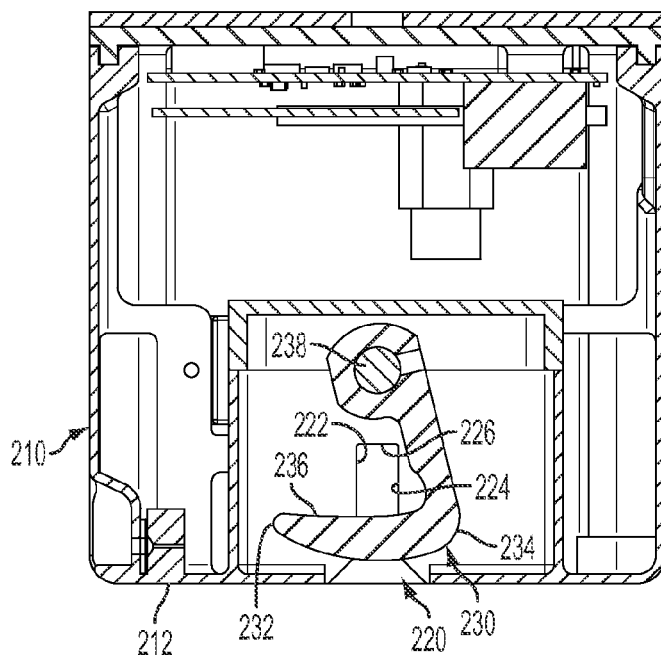


FIG. 2D

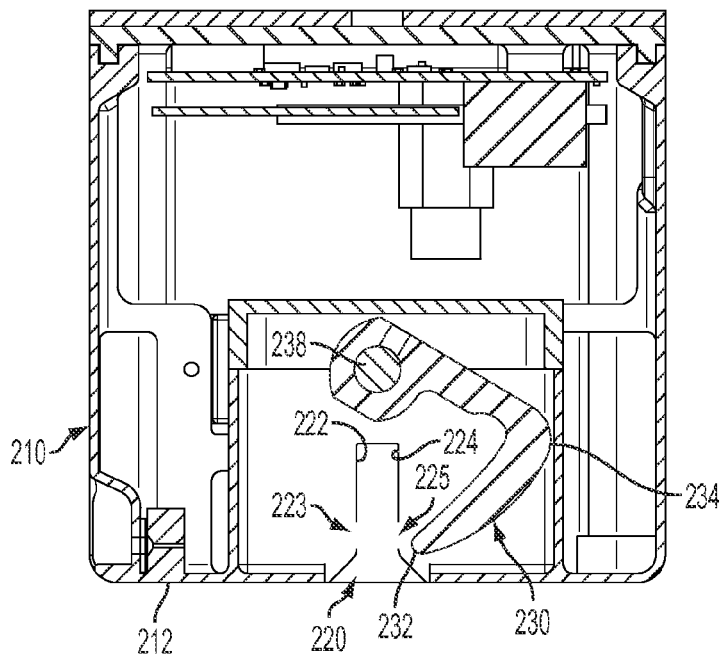


FIG. 2E

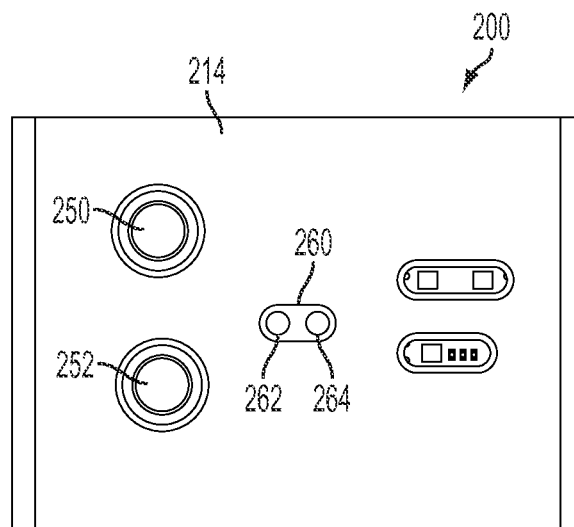


FIG. 2F

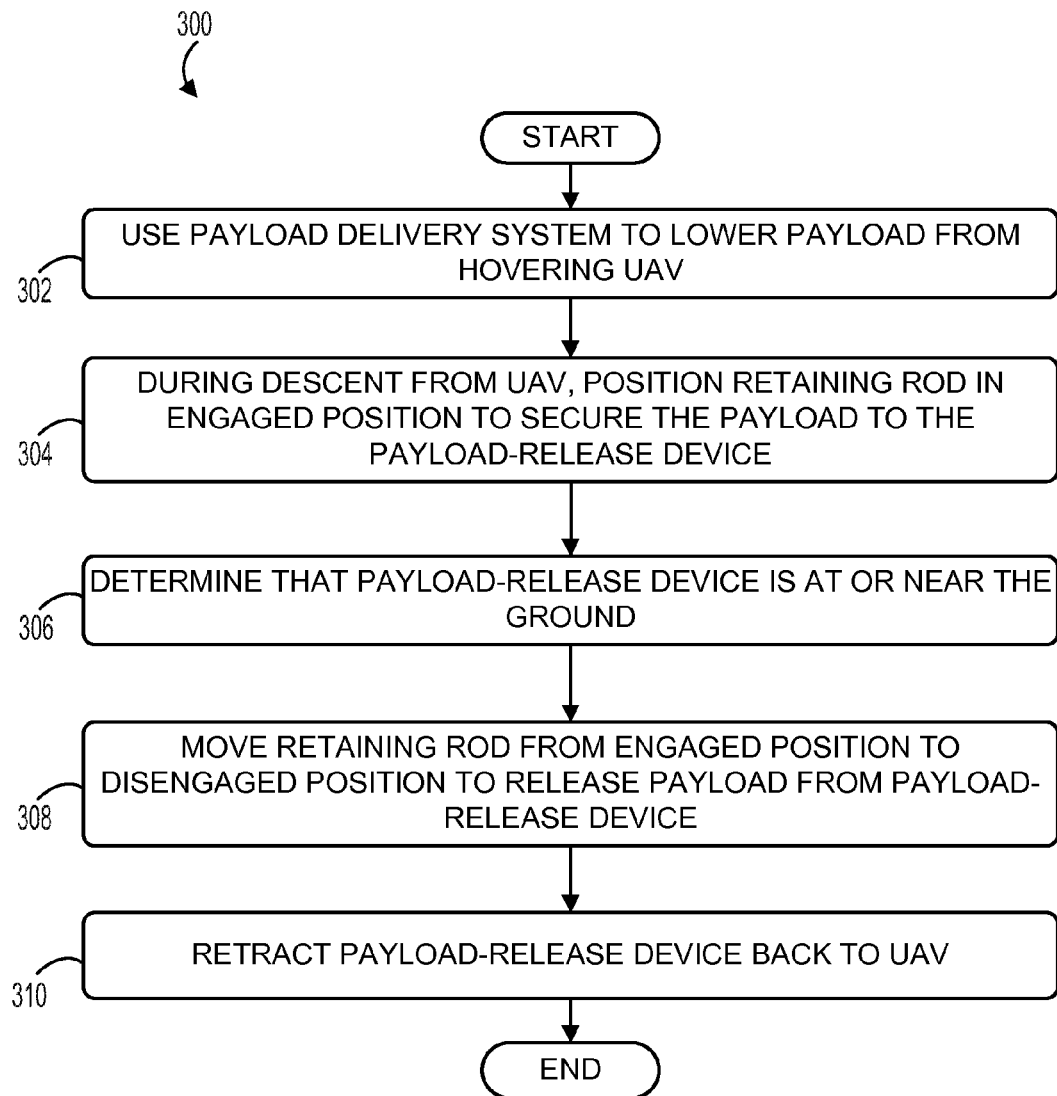


FIG. 3A



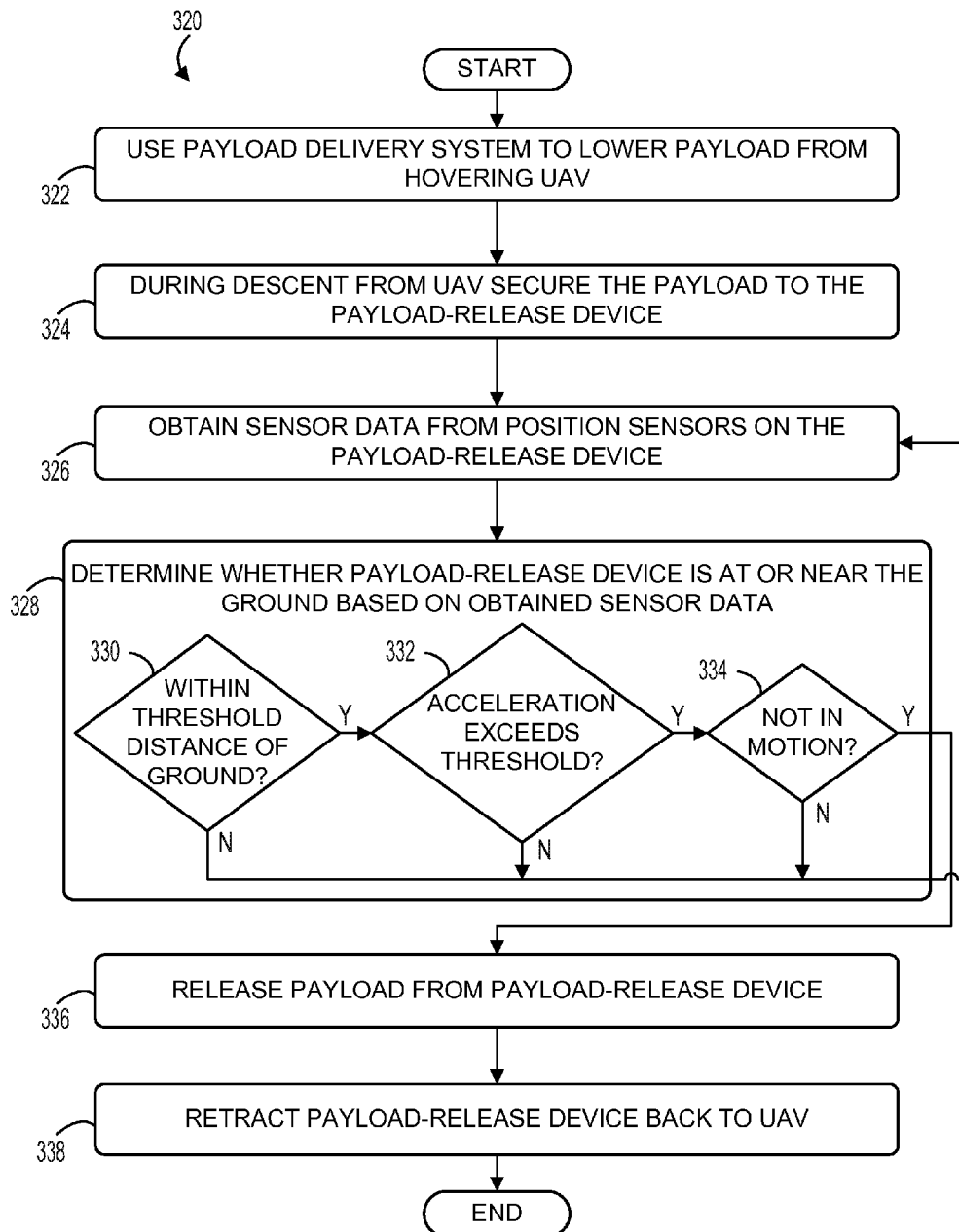


FIG. 3B

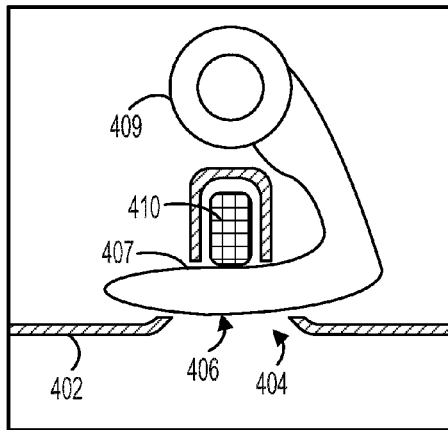


FIG. 4A

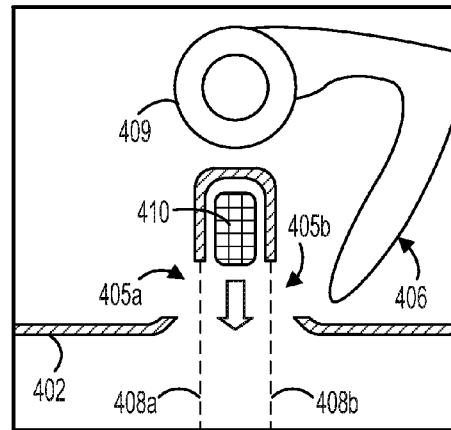


FIG. 4B

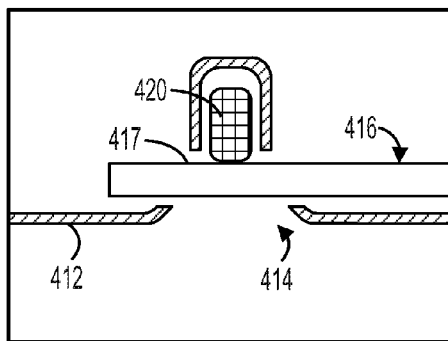


FIG. 4C

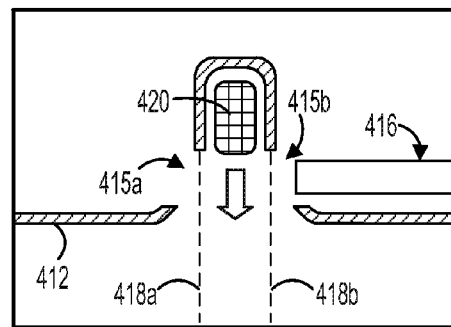


FIG. 4D

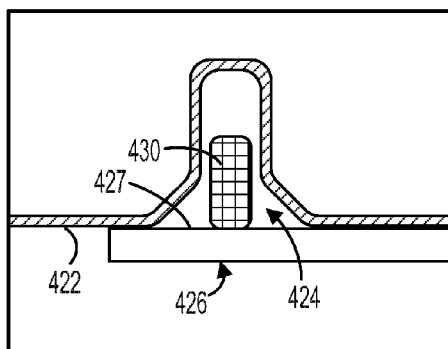


FIG. 4E

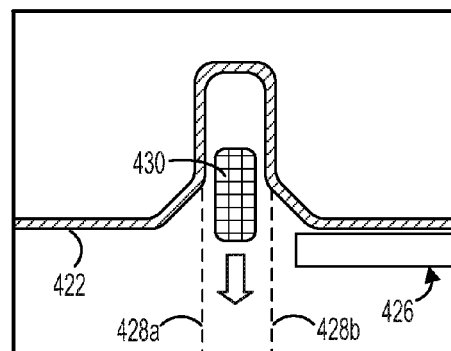


FIG. 4F

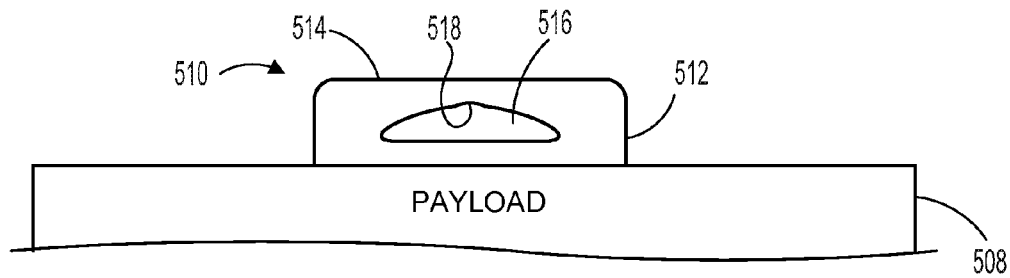


FIG. 5A

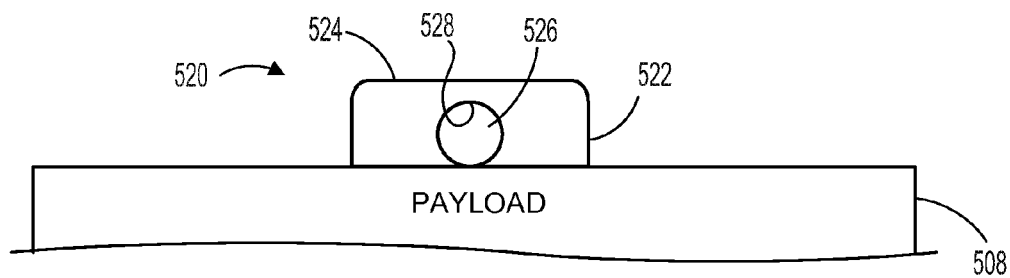


FIG. 5B

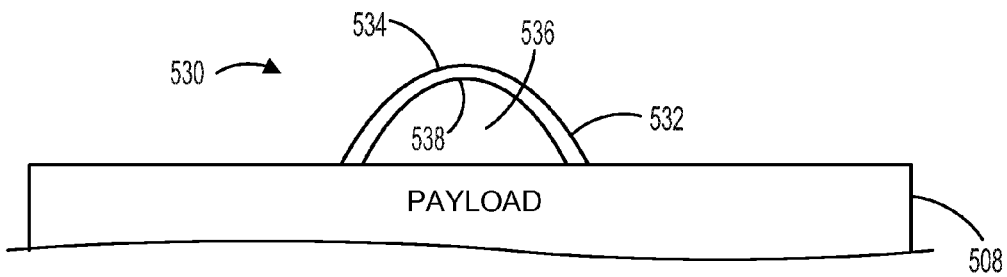


FIG. 5C

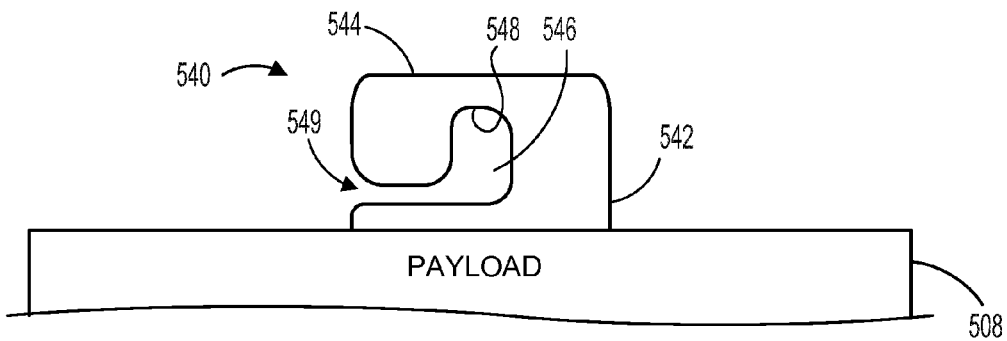


FIG. 5D

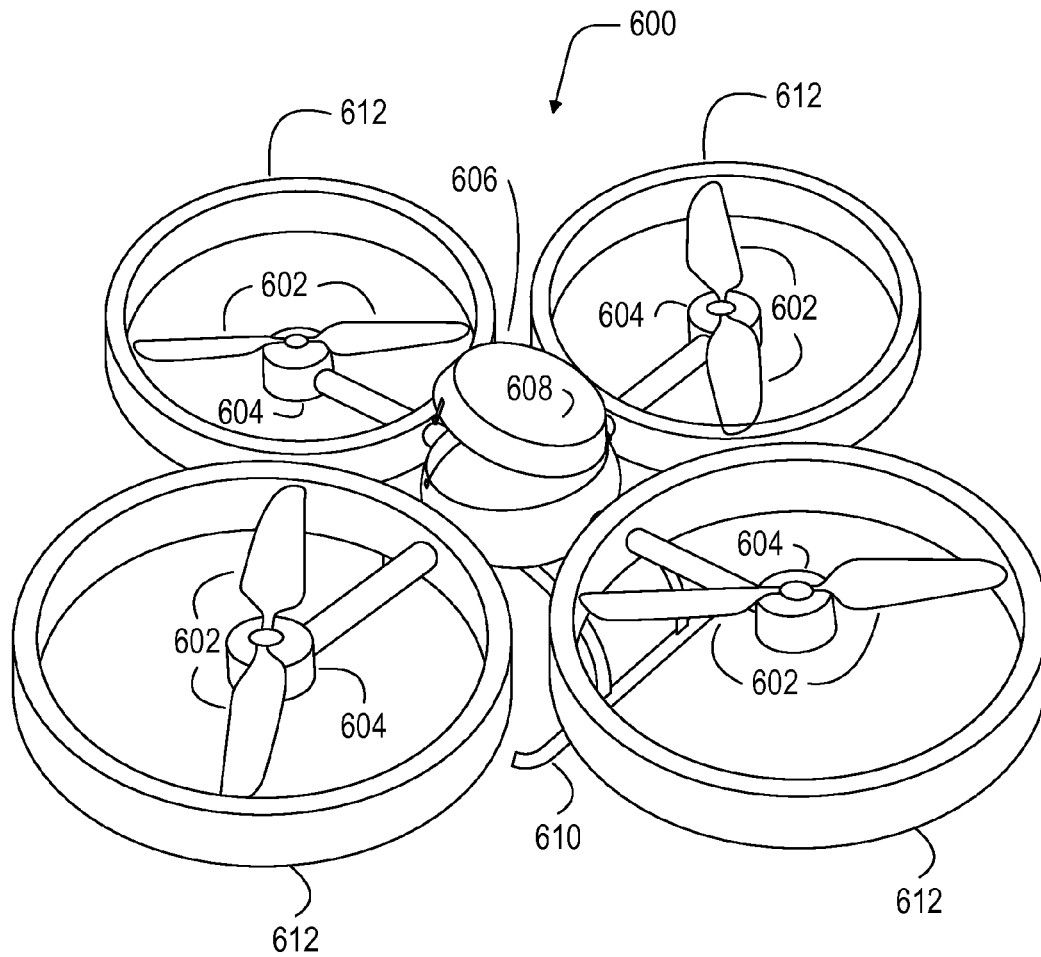


FIG. 6A

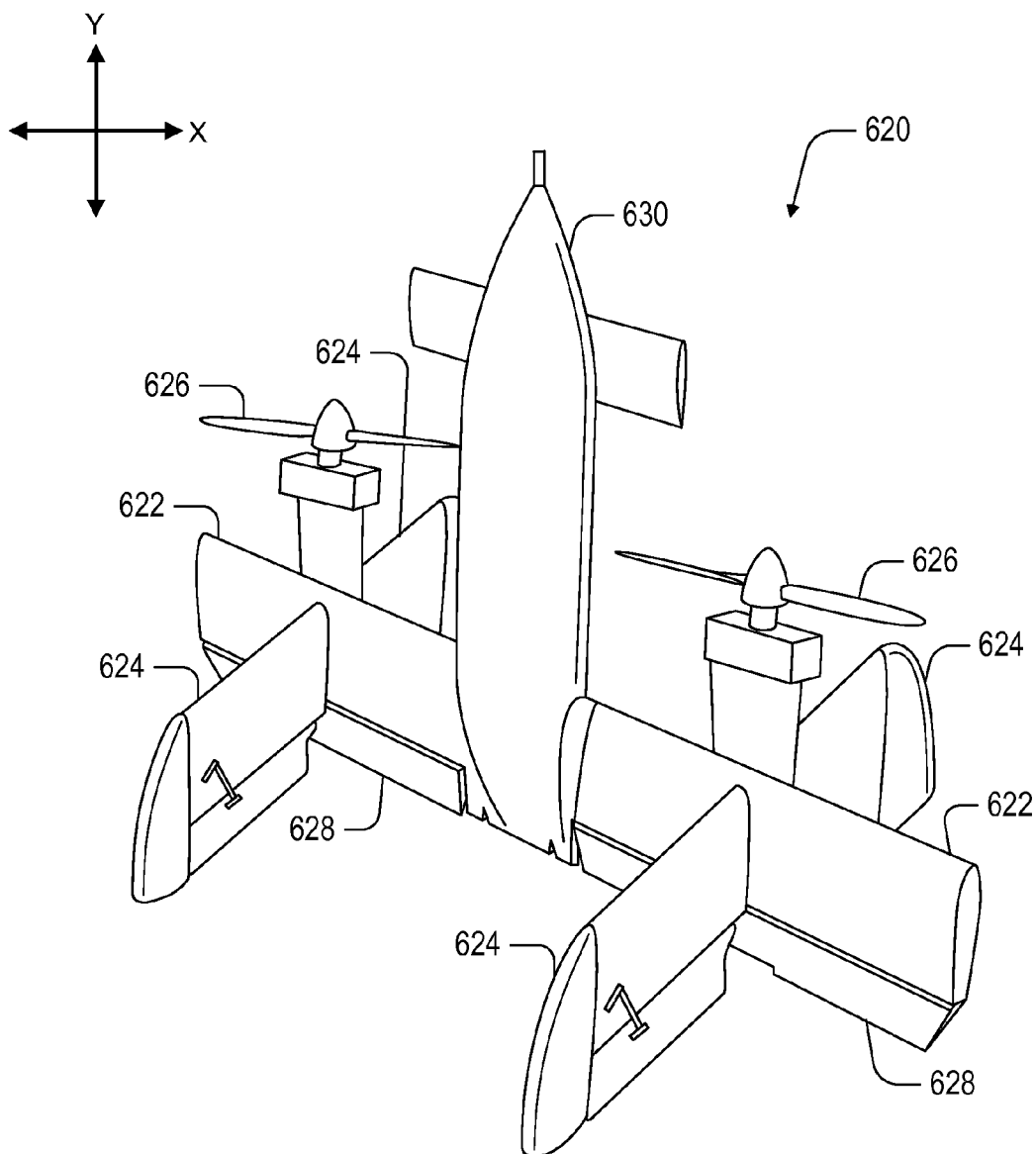


FIG. 6B

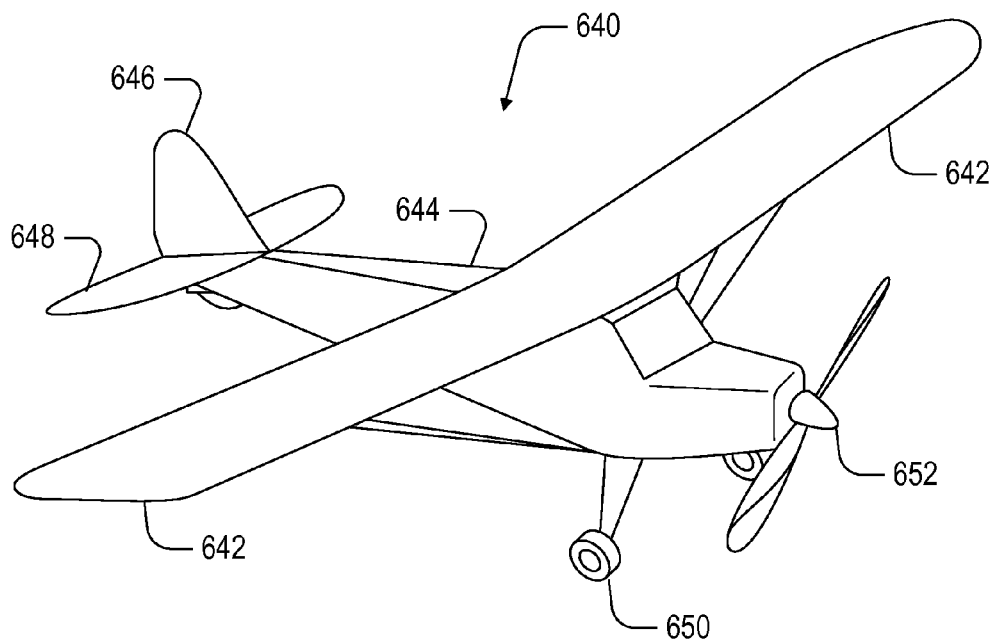


FIG. 6C

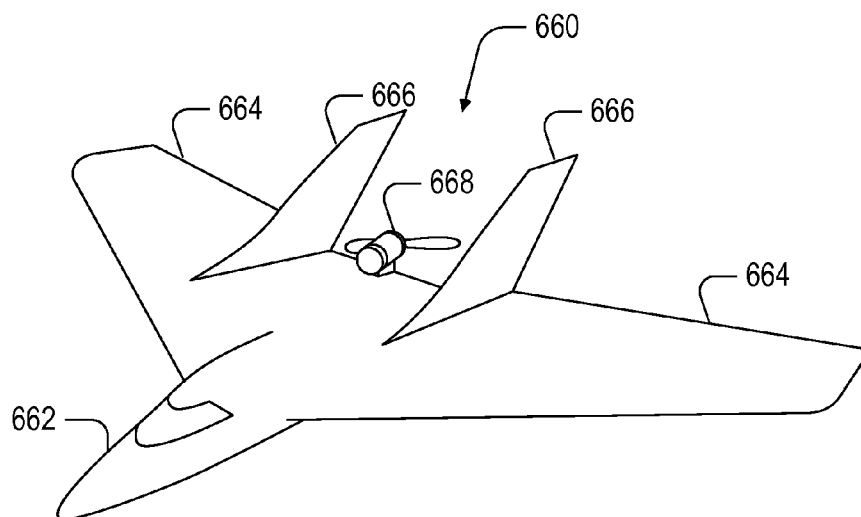


FIG. 6D

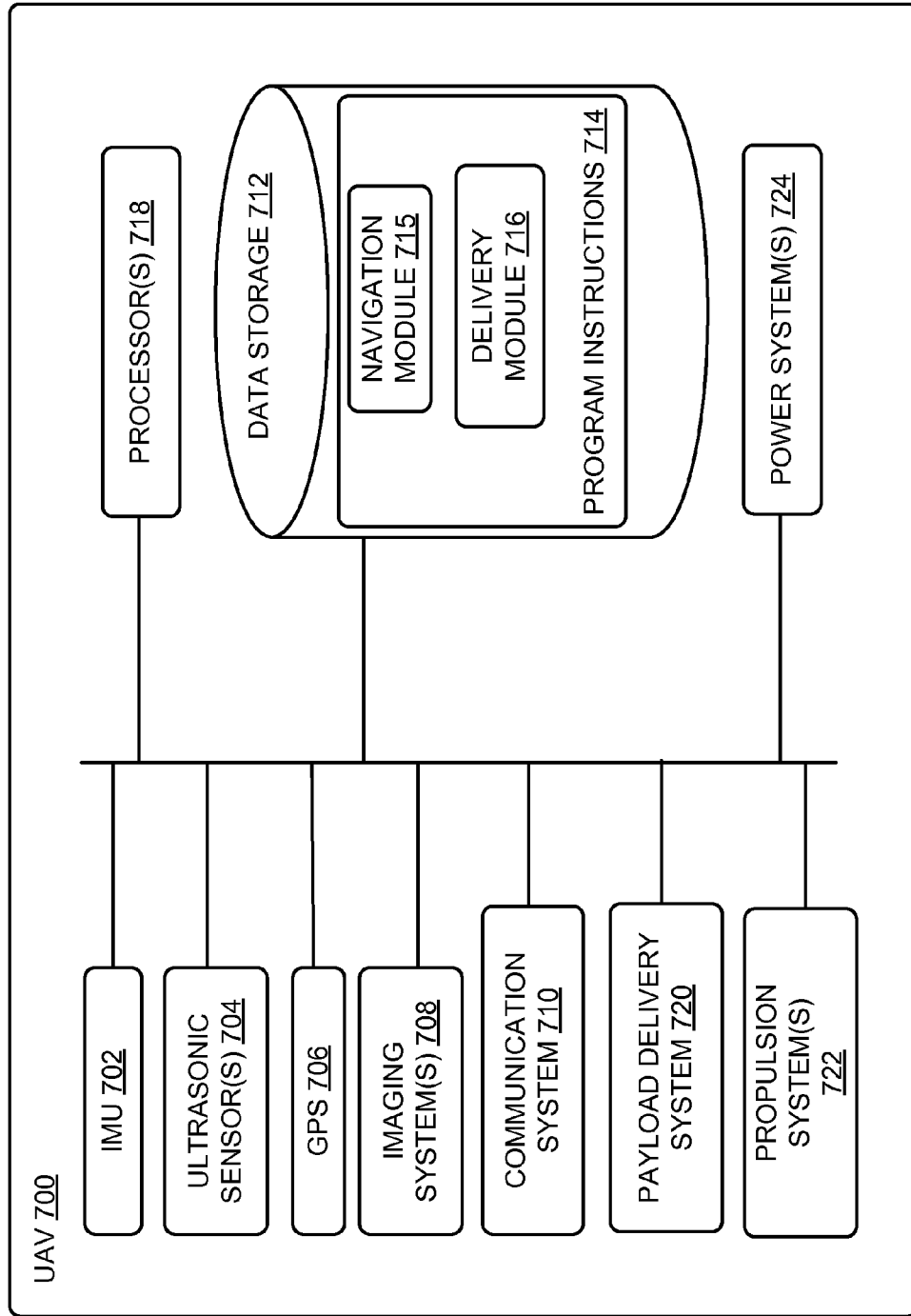
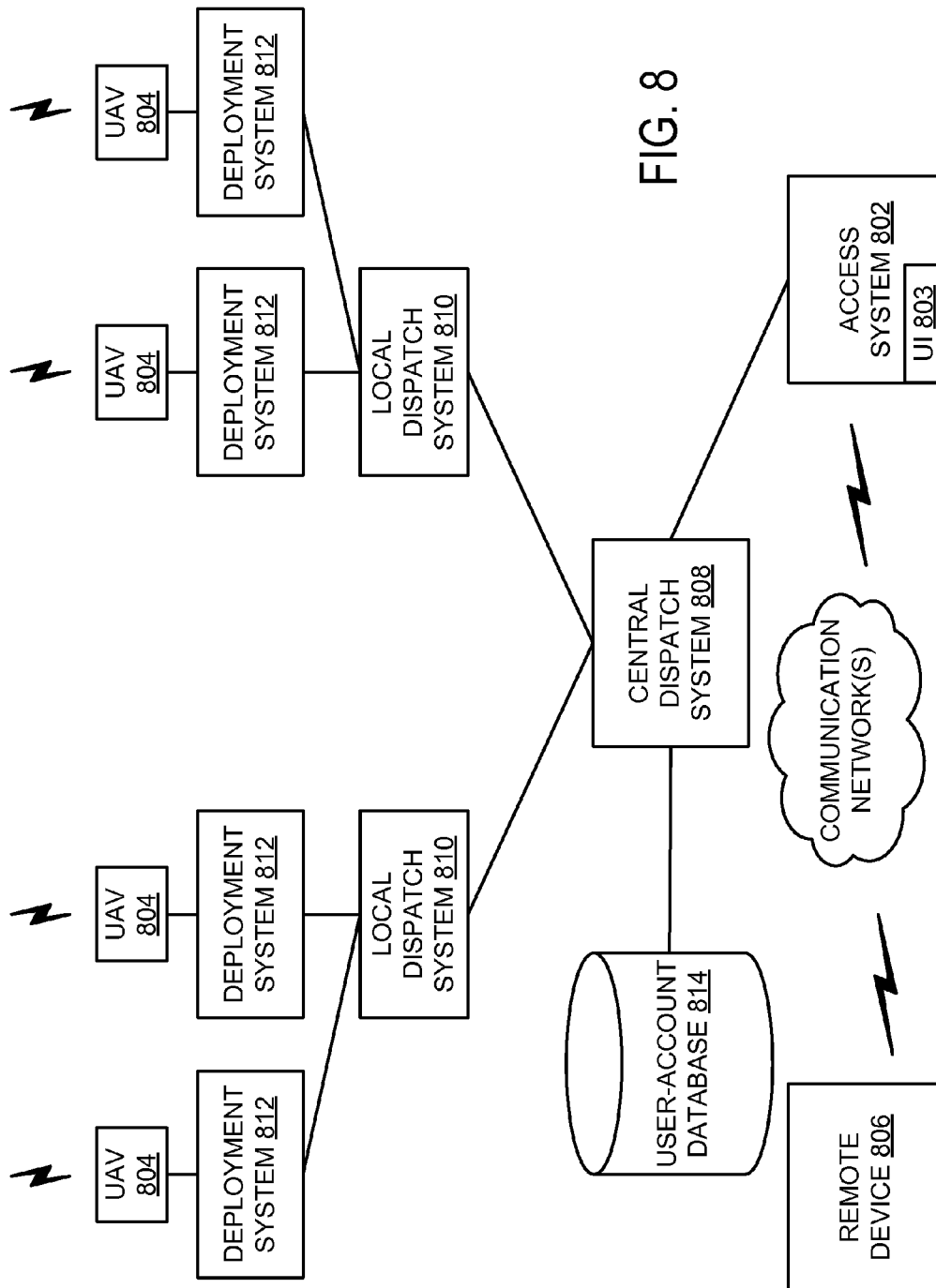


FIG. 7





1

## PAYLOAD-RELEASE DEVICE AND OPERATION THEREOF

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/584,181, filed on Dec. 29, 2014, which claims priority to U.S. Provisional Patent Application No. 62/043,396, filed on Aug. 28, 2014, both of which are incorporated herein by reference in their entirety and for all purposes.

### BACKGROUND

Unless otherwise indicated herein, the materials described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

An unmanned vehicle, which may also be referred to as an autonomous vehicle, is a vehicle capable of travel without a physically-present human operator. An unmanned vehicle may operate in a remote-control mode, in an autonomous mode, or in a partially autonomous mode.

When an unmanned vehicle operates in a remote-control mode, a pilot or driver that is at a remote location can control the unmanned vehicle via commands that are sent to the unmanned vehicle via a wireless link. When the unmanned vehicle operates in autonomous mode, the unmanned vehicle typically moves based on pre-programmed navigation waypoints, dynamic automation systems, or a combination of these. Further, some unmanned vehicles can operate in both a remote-control mode and an autonomous mode, and in some instances may do so simultaneously. For instance, a remote pilot or driver may wish to leave navigation to an autonomous system while manually performing another task, such as operating a mechanical system for picking up objects, as an example.

Various types of unmanned vehicles exist for various different environments. For instance, unmanned vehicles exist for operation in the air, on the ground, underwater, and in space. Unmanned vehicles also exist for hybrid operations in which multi-environment operation is possible. Examples of hybrid unmanned vehicles include an amphibious craft that is capable of operation on land as well as on water or a floatplane that is capable of landing on water as well as on land.

### SUMMARY

An unmanned aerial vehicle (UAV) is disclosed that includes a retractable payload delivery system. The payload delivery system can lower a payload to the ground using a delivery device that secures the payload during descent and releases the payload upon reaching the ground. The delivery device can include a channel in which a payload mount attachment for a payload can be inserted. The payload-mount attachment can include an aperture for receiving a retaining rod to secure the attachment, and thus the payload, to the delivery device. The retaining rod can assume either an engaged position, in which a portion of the retaining rod engages the payload mount attachment when the payload mount attachment is inserted in the channel, or a disengaged position, in which the retaining rod does not engage the payload mount attachment.

In one aspect, an example delivery device may include a housing, a retaining rod, and a control system. The housing can include a channel configured to receive a payload mount attachment of a payload. The housing can also include a tether

2

anchor configured to couple the housing to a tether operable to suspend the housing via the tether. The retaining rod can be coupled to the housing. The retaining rod can be configured to be positioned in: (i) a first position in which a portion of the retaining rod engages the payload mount attachment when the payload mount attachment is inserted in the channel, and (ii) a second position in which the retaining rod does not engage the payload mount attachment. The control system can be configured to position the retaining rod in the first position to engage the payload mount attachment and secure the payload to the delivery device during a delivery operation in which the delivery device is lowered to the ground via the tether. The control system can also be configured to determine that the delivery device is at or near the ground. The control system can also be configured to move the retaining rod from the first position to the second position such that the payload is released from the delivery device in response to determining that the delivery device is at or near the ground.

In another aspect, an example method may include, while a delivery device is being lowered from an unmanned aerial vehicle (UAV) via a tether coupled to the delivery device and the UAV, receiving sensor data that is generated by one or more sensors arranged on or within the delivery device. The sensor data can be indicative of a position of the delivery device. The example method can also include determining that the delivery device is at or near the ground. Determining that the delivery device is at or near the ground can include: (i) determining, based at least in part on the received sensor data, that the delivery device is within a threshold distance of the ground; (ii) in response to determining that the delivery device is within the threshold distance of the ground, determining, based at least in part on the received sensor data, that an instantaneous acceleration of the delivery device exceeds a first threshold; and (iii) subsequent to determining that the instantaneous acceleration of the delivery device exceeds the first threshold, determining, based at least in part on the received sensor data, that the instantaneous acceleration of the delivery device is less than a second threshold. The second threshold can be lower than the first threshold. The example method can also include releasing a payload from the delivery device in response to determining that the delivery device is at or near the ground.

In another aspect, an example system may include a retractable delivery system, and a control system. The retractable delivery system may include a delivery device releasable coupled to a payload. The retractable delivery system can also include one or more sensors arranged on or within the delivery device. The one or more sensors can be configured to generate sensor data indicative of a position of the delivery device. The retractable delivery system can also include a tether coupled to an unmanned aerial vehicle (UAV) and the delivery device. The retractable delivery system can also include a retraction system coupled to the tether and operable to lower the delivery device from the UAV. The control system can be configured to use the retractable delivery system to initiate delivery while the UAV hovers over a delivery location. Initiating delivery can include lowering the delivery device from the UAV while the delivery device is secured to the payload such that the payload descends from the UAV. The control system can also be configured to receive sensor data from the one or more sensors. The control system can also be configured to determine that the delivery device is at or near the ground based at least in part on the received sensor data. Determining that the delivery device is at or near the ground can include: (a) determining, based at least in part on the received sensor data, that the delivery device is within a threshold distance of the ground; (b) in response to determin-

3

ing that the delivery device is within the threshold distance of the ground, determining, based at least in part on the received sensor data, that an instantaneous acceleration of the delivery device exceeds a first threshold; and (c) subsequent to determining that the instantaneous acceleration of the delivery device exceeds the first threshold, determining, based at least in part on the received sensor data, that the instantaneous acceleration of the delivery device is less than a second threshold, wherein the second threshold is lower than the first threshold. The control system can also be configured to cause the retractable delivery system to release the payload from the delivery device in response to determining that the payload is at or near the ground.

In another aspect, a non-transitory computer readable medium has stored therein instructions executable by a computing device to cause the computing device to perform operations. The operations may include, while a delivery device is being lowered from an unmanned aerial vehicle (UAV) via a tether coupled to the delivery device and the UAV, receiving sensor data that is generated by one or more sensors arranged on or within the delivery device. The sensor data can be indicative of a position of the delivery device. The operations may also include determining that the delivery device is at or near the ground. Determining that the delivery device is at or near the ground can include: (i) determining, based at least in part on the received sensor data, that the delivery device is within a threshold distance of the ground; (ii) in response to determining that the delivery device is within the threshold distance of the ground, determining, based at least in part on the received sensor data, that an instantaneous acceleration of the delivery device exceeds a first threshold; and (iii) subsequent to determining that the instantaneous acceleration of the delivery device exceeds the first threshold, determining, based at least in part on the received sensor data, that the instantaneous acceleration of the delivery device is less than a second threshold. The second threshold can be lower than the first threshold. The operations may also include releasing a payload from the delivery device in response to determining that the delivery device is at or near the ground.

In yet another aspect, example systems may include means for, while a delivery device is being lowered from an unmanned aerial vehicle (UAV) via a tether coupled to the delivery device and the UAV, receiving sensor data that is generated by one or more sensors arranged on or within the delivery device. Example systems may also include means for determining that the delivery device is at or near the ground. Example systems may also include means for releasing a payload from the delivery device in response to determining that the delivery device is at or near the ground.

These as well as other aspects, advantages, and alternatives, will become apparent to those of ordinary skill in the art by reading the following detailed description, with reference where appropriate to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A, 1B, and 1C show a UAV that includes a payload delivery system, according to an example embodiment.

FIG. 1D is a simplified block diagram of an example payload-release device, according to an example embodiment.

FIG. 2A is an aspect view of an example payload-release device.

FIGS. 2B and 2C are side views of the example payload-release device aligned to engage a payload, and secured to the payload, according to example embodiments.

4

FIGS. 2D and 2E are side cross-sectional views of the payload-release device retaining hook in an engaged position and in a disengaged position, according to example embodiments.

FIG. 2F is a top view of the example payload-release device, according to an example embodiment.

FIGS. 3A and 3B are flowcharts of example processes that can be performed by a payload delivery system during a delivery operation, according to example embodiments.

FIGS. 4A, 4B, 4C, 4D, 4E, and 4F illustrate alternate payload-release device configurations in engaged and disengaged positions, according to example embodiments.

FIGS. 5A, 5B, 5C, and 5D illustrate alternate payload mount attachment configurations, according to example embodiments.

FIGS. 6A, 6B, 6C, and 6D are simplified illustrations of example unmanned aerial vehicles, according to example embodiments.

FIG. 7 is a simplified block diagram illustrating components of a UAV, according to an example embodiment.

FIG. 8 is a simplified block diagram illustrating a distributed UAV system, according to an example embodiment.

#### DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying figures, which form a part hereof. In the figures, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, figures, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

#### I. OVERVIEW

Example embodiments may relate to and/or be implemented in a system in which unmanned vehicles, and in particular, “unmanned aerial vehicles” (UAVs), are configured to deliver payloads at delivery locations. UAVs in such a system may operate in an autonomous or semi-autonomous delivery system in which the UAV carries a payload from a first location, such as a distribution center, to a delivery location, such as a residence or business. At the distribution center, the UAV can be loaded with the payload to be delivered, and then the UAV can navigate to the delivery location. The UAV can then transition to a hover mode while situated above the delivery location.

While hovering, the UAV can autonomously deliver the payload using a retractable delivery system that lowers the payload to the ground while the UAV hovers above. The delivery system can include a payload-release device coupled to the UAV by a tether. The payload-release device is an apparatus that functions to secure a payload during descent from a hovering UAV, and then release the payload on the ground, among other functions described herein. The payload-release device is alternately referred to herein as a delivery device. A winch can unreel and reel in the tether to lower and raise the payload-release device. The payload-release device can be configured to secure the payload while being lowered from the UAV by the tether and release the payload upon reaching ground level. The payload can then be

5

retracted to the UAV by reeling in the tether using the winch. The payload-release device can also include sensors such as a barometric pressure based altimeter and/or accelerometers to assist in detecting the position of the payload-release device (and the payload) relative to the ground. Data from the sensors can be communicated back to the UAV and/or a control system over a wireless link and used to help in determining when the payload-release device has reached ground level (e.g., by detecting a measurement with the accelerometer that is characteristic of ground impact).

The payload-release device can be secured to the payload in a variety of ways. In some examples, the payload includes a payload mount attachment on its top surface. The payload mount attachment can be a loop extending from the top surface, a hook, or a structure with an aperture. The payload-release device can include a channel into which the payload mount attachment can be inserted. The payload-release device can also include a retaining rod or hook that can be positioned to engage the payload mount attachment and release the payload mount attachment. The retaining rod can be configured to be positioned in: (i) an engaged position, in which the retaining rod intersects two planes defined by respective sidewalls of the channel, and (ii) a disengaged position, in which the retaining rod does not intersect either plane. For example, in the engaged position, the retaining rod can cross the channel such that the rod engages a rim of the payload mount attachment inserted in the channel. In the disengaged position, the retaining rod can be withdrawn from the channel such that the rod does not interfere with the payload mount attachment exiting the channel. Thus, in the disengaged position, the retaining rod does not engage the payload mount attachment.

Some aspects involve determining when to actuate the retaining rod to release the payload (i.e., determining when the payload is at or near the ground). To make such a determination, the payload-release device can descend from the UAV until it reaches a threshold distance from the ground, then determine whether accelerometer measurements exceed a threshold, and then, following detection of a threshold accelerometer measurement, determine whether sensor data indicates the payload-release device is at rest. The determination that the payload-release device is within a threshold distance from the ground may be based on, for example, data from an encoder on the winch and/or an IMU and/or altimeter on the payload-release device.

After releasing the payload by actuating the retaining rod or hook, the payload-release device can request to be withdrawn to the UAV via wireless communication, which causes the winch to retract the payload-release device. In some cases, the accelerometer threshold information may be one source of information that is weighted along with other sources of delivery-indicative information to determine the payload has reached ground. Other information sources may be from encoders on the winch, line-tension sensors, thrusters on the UAV, imaging system on the UAV, active range sensors on the payload-release device, among other examples.

## II. EXAMPLE SYSTEM FOR DELIVERING A PAYLOAD FROM A HOVERING UAV

FIGS. 1A, 1B, and 1C show a UAV 100 that includes a payload delivery system 110, according to an example embodiment. As shown, payload delivery system 110 for UAV 100 includes a tether 102, a tether-deployment mechanism 104, and a payload-release device 106 coupled to the tether 102. The payload-release device 106 can function to alternately secure a payload 108 and release the payload 108

6

upon delivery. The tether-deployment mechanism 104 can function to unreel and retract the tether 102 such that the payload-release device 106 can be lowered to the ground and retracted back to the UAV 100. The payload 108 may itself be an item for delivery, and may be housed within (or otherwise incorporate) a parcel, container, or other structure that is configured to interface with the payload-release device 106. In practice, the payload delivery system 110 of UAV 100 may function to autonomously lower payload 108 to the ground in a controlled manner to facilitate delivery of the payload 108 on the ground while the UAV 100 hovers above.

As shown in FIG. 1A, the payload delivery system 110 may function to hold the payload 108 against or close to the bottom of the UAV 100, or even inside the UAV 100, during flight from a launch site to a target location 120. The target location 120 may be a point in space directly above a desired delivery location. Then, when the UAV 100 reaches the target location 120, the UAV's control system may operate the tether-deployment mechanism 104 such that the payload 108, secured by the payload-release device 106, is suspended by the tether 102 and lowered to the ground, as shown in FIG. 1B. In an example, a control system detects that the payload 108 has been lowered to a point where it is at or near the ground (e.g., at the delivery location). In response to detecting the payload 108 is at or near the ground, the control system may operate the payload-release device 106 to release the payload 108, and thereby detach the payload 108 from the tether 102. After releasing the payload 108, the control system can operate the tether-deployment mechanism 104 to retract the payload-release device 106 to the UAV 100, as shown in FIG. 1C. For example, the tether-deployment mechanism 104 may include a winch that reels the tether 102 on and off of a spool to lower and raise the payload-release device 106.

The control system may use various types of data, and various techniques, to determine when the payload 108 and/or payload-release device 106 have lowered to be at or near the ground. Further, the data that is used to determine when the payload 108 is at or near the ground may be provided by sensors on UAV 100, sensors on the tether 102, sensors on the payload-release device 106, and/or other data sources that provide data to the control system. The control system itself may be situated on the payload-release device 106 and/or on the UAV 100. For example, the payload-release device 106 may include logic module(s) implemented via hardware, software, and/or firmware that cause the payload-release device 106 to function as described herein, and the UAV 100 may include logic module(s) that communicate with the payload-release device 106 to cause the payload-release device 106 to perform functions described herein.

### A. Tether

In practice, the tether 102 used to suspend the payload-release device 106 (and payload 108) from the UAV 100 may be formed from a variety of materials. The tether 102 may include, for example, high tensile-strength polymeric fibers, metallic and/or synthetic cables, and other materials that exhibit relatively high tensile-strength per unit weight. The tether 102 may also be selected, at least in part, to be a material that is suitable for interfacing with the tether-deployment mechanism 104. In some examples, the tether 102 may also be operable for transmitting information between the payload-release device 106 and the UAV 100. For instance, the tether 102 may include, or be coupled to, a data-transmission wire formed of a conductive material (e.g., for conveying data-encoded electrical signals) and/or a fiber optic line (e.g., for conveying data-encoded optical signals).

### B. Tether-Deployment Mechanism

In an example the tether-deployment mechanism **104** may include or take the form of a winch that is configured to deploy the tether with a payload attached thereto (e.g., via the payload-release device **106**). Such a winch may include a motor (e.g., a DC motor) that can be actively controlled by a servomechanism (also referred to as a “servo”) and a microcontroller. The microcontroller may output a desired operating rate (e.g., a desired RPM) for the winch, which may correspond to the speed at which the payload **108** should be lowered towards the ground. The servo may then control the winch so that it operates at a desired rate. In addition, the winch can be used to retract the tether **102** and the payload-release device **106** attached thereto following delivery of the payload **108**. Thus, the winch may function to reverse its direction of rotation to achieve retraction.

In some cases, the tether-deployment mechanism **104** may incorporate or be associated with an encoder that senses rotation of the spool letting out (or reeling in) the tether **102**. Data from such an encoder can then be used by a control system of the UAV **100** to help in determining the distance between the payload **108** and the ground as the payload **108** is being lowered.

In addition, the tether-deployment mechanism **104** may vary the rate at which the payload **108** is lowered to the ground or the rate at which the payload-release device **106** is retracted back to the UAV **100**. For example, a microcontroller may change the desired rate of lowering and/or retraction according to a variable rate profile and/or in response to other factors in order to change the rate at which the payload **108** descends towards the ground. To do so, the tether-deployment mechanism **104** may adjust the amount of braking or the amount of friction that is applied to the tether. For example, to vary the deployment rate, the tether-deployment mechanism **104** may include friction pads that can apply a variable amount of pressure to the tether. As another example, a line-deployment mechanism **104** can include a motorized braking system that varies the rate at which a spool unwinds the tether **102** during lowering, or reels in the tether **102** during retraction, by making adjustments to a motor speed (e.g., RPM) or gearing applied to the motor. Other examples are also possible.

In some examples, the tether-deployment mechanism **104** may be attached to the payload-release device **106**, which is lowered with the payload **108**, rather than being secured to a housing of the UAV **100**. For example, a winch could be attached to the top of the payload-release device **106**. In such an example, the winch may be operable to hold the payload-release device **106** (and the payload **108**) at or near the bottom of the UAV **100** during flight to the delivery location. Then, upon arriving at the delivery location, the winch may function to lower the payload **108** by sliding along the tether **102** and/or using a brake to adjust the rate at which the tether **102** is released in accordance with a variable rate. Moreover, in an example that omits the payload-release device **106**, such a top-mounted winch may be mounted directly to the payload **108**.

### C. Payload-Release Device

FIG. 1D is a simplified block diagram of the payload-release device **106**. The payload-release device **106** may take different forms in different implementations. The device **106** can be connected to the UAV **100** by the tether **102**, and the tether-deployment mechanism **104** on the UAV (e.g., a winch) can reel and unreel the tether **102** to raise and lower the device **106** during a delivery operation. The payload-release device **106** can be suspended from the UAV **100** using the tether **102** and can function to alternately secure the payload

**108** (e.g., during descent from the UAV) and release the payload **108** (e.g., upon reaching the ground).

As shown in FIG. 1D, the payload-release device **106** may include various systems and components, although one or more systems and/or components may be omitted and/or modified in some examples. For example, the payload-release device **106** may include a processing system **120**, a memory **122**, a communication system **128**, a power supply **132**, a bystander communication module **136**, UAV tracking features **140**, position sensor(s) **150**, a translational position system **160**, and a payload release system **170**, each of which may be mounted on or within a housing of the device **106** and communicatively coupled to one another. In some examples, the payload **108** and/or payload-release device **106** may be designed with features that help to prevent the payload **108** and/or the payload-release device **106** from getting stuck or caught during descent (e.g., to prevent getting caught and/or tangled in a tree or on a power line). For instance, the payload **108** and/or payload-release device **106** may take the form of or be housed in a teardrop-shaped housing, or another shape that can incorporate surfaces that move obstacles aside so as to allow the payload-release device **106** to be more easily moved up and down by the tether **102** without getting stuck.

#### i. Processing System

The processing system **120** may be configured to provide various functions described herein. The processing system **120** may include or take the form of program instructions stored in a non-transitory computer-readable medium (e.g., the memory **122**) and may also include a variety of functional modules implemented by software, firmware, and/or hardware.

The processing system **120** may include one or more general purpose or special purposes microprocessors in communication with memory **122**. Memory **122** may include a non-transitory computer-readable medium. In practice, the processing system **120** may cause the payload-release device **106** to perform certain functions by executing program instructions **124** stored in memory **122**. For instance, upon execution of the program instructions **122**, the processing system **120** may obtain sensor data from the position sensors **150**, and generate command signals that cause an actuator **172** of the payload release system **170** to move so as to engage or disengage the payload **108** based on characteristics of the obtained sensor data. In some cases, the processing system **120** may additionally or alternatively include hardware-implemented and/or firmware-implemented logic modules. The memory **122** can also include data **126**, which may be used to store information particular to the specific payload-release device **106**. For instance, the data **126** may include information related to a model number and/or serial number of the device **106** and/or information related to calibration of the position sensors **150** (or other systems), or operation of other systems in the payload-release device **106** (e.g., communication protocols used by the communication system **128**).

#### ii. Communication System

The communication system **128** can be used to send and receive data between the payload-release device **106** and the UAV **100**. For example, the communication system **128** may be a wireless communication system that sends and receives data-encoded electromagnetic transmissions using an antenna to create a wireless data link **130** with the UAV **100**.

The communication system **128** can function to send and receive information to and from the UAV **100**. In some examples, the communication system **128** can include an antenna structure and can operate to exchange information with the UAV via a wireless communication link **130**. The

communication system **128** may additionally or alternatively send and receive information over a wireline link, such as a data transmission link incorporated with the tether **102**. The communication system **128** may also include a modem for modulating and demodulating signals transmitted to and from the UAV **100**. Among other features, the communication system **128** can allow for a control system associated with the UAV **100** to access information generated by sensors in the payload-release device **106** and vice versa. Additionally, the communication system **128** can allow for determinations related to operation of the payload-release device to be made by the processing system **120** in the payload-release device **106** and/or by a control system associated with the UAV **100** (e.g., a control system on the UAV **100** and/or a control system in communication with the UAV **100**).

### iii. Power Supply

The payload-release device **106** can include various systems and/or components that consume electrical power, such as the sensors **150**, the communication system **128**, the processing system **120**, etc. The power supply **132** can provide power to such systems in the payload-release device **106**. The power supply **132** may include a battery **134** and/or a capacitive device that can be charged with electrical energy, for example. The battery **134** may be charged through charging terminals **135** accessible from the exterior of the payload-release device **106**. In some examples, the charging terminals **135** may include conductive pads that are arranged to electrically couple to corresponding terminals on the UAV **100** while the payload-release device **106** is secured to the UAV **100** (e.g., during flight mode operations of the UAV). For example, the charging terminals **135** may electrically couple to corresponding terminals on the UAV **100** when the payload-release device **106** is seated against the UAV **100**. The battery **134** within the payload-release device **106** can then be recharged via the electrical connection.

Moreover, in some examples, such an electrical connection between the payload-release device **106** and the UAV **100** may be facilitated by the payload-release device **106** including an asymmetric surface that is received within a corresponding mating surface of the UAV **100** (e.g., a relief of the asymmetric surface). As the payload-release device **106** is being retracted toward the UAV **100**, the asymmetric surface can interface with the mating surface to cause the payload-release assembly to rotate to a particular orientation at which the asymmetric surface is aligned with the mating surface. By ensuring the payload-release device **106** becomes seated against the UAV **100** in a repeatable orientation, the electrical contacts/terminals between the device **106** and the UAV **100** can be aligned for electrical connection. The asymmetric surface and/or mating surface may also include guide pins and corresponding receiving channels to facilitate self-alignment of the electrical contacts as the payload-release device **106** approaches the UAV **100**. Additionally or alternatively, the electrical contacts/terminals may be arranged to be at least partially rotation insensitive. For example, a surface of the payload-release device **106** that is seated against the UAV **100** may be cylindrically symmetric (e.g., a conical surface) and be received into a corresponding mating surface on the UAV. The contacts/terminals may include cylindrically symmetric conductive rings at respective radii of the two cylindrically symmetric mating surfaces. As a result, the electrical contact between the respective terminals may be achieved regardless of the rotational orientation of the payload-release device **106**. Other examples of self-aligned and/or rotation insensitive electrical and/or communication terminals between the payload-release device **106** and the UAV **100** are also possible.

In another example, the payload-release device **106** may be charged wirelessly. In particular, both the UAV **100** and the payload-release device **106** can include antennas for sending and harvesting energy, respectively. The UAV's power supply antenna may be situated along the exterior surface of the UAV or within the UAV, near the mating location where the payload-release device **106** is seated during flight mode. Similarly, the payload-release device **106** can have an energy-harvesting antenna situated near the surface of the payload-release device that is seated against the UAV **100** during flight mode. To charge the payload-release device, the power supply antenna can transmit energy at a particular power. The radiated energy induces voltage variations across the energy harvesting antenna in the payload-release device, and those voltage variations can be regulated and/or rectified by electronics therein to supply a charging current to the battery or other power supply module within the payload-release device. Among other benefits, a wireless charging connection may allow for relatively greater alignment tolerances between the payload-release device **106** and the mating surface of the UAV **100** that the payload-release device **106** is withdrawn to during flight mode. A wireless charging connection may also decrease the number of exposed electrical terminals required on the payload-release device, which may enhance durability and weather-resistance. Further, the power supply antenna and the energy-harvesting antenna may be configured to enhance the efficiency of power transfer from the power supply antenna and the energy-harvesting antenna, such as by an impedance matching technique, for example.

In some cases, the payload-release device **106** may additionally or alternatively be powered via electrical signals conveyed over the tether **102** (or another conductive linkage between the UAV **100** and the payload-release device **106**).

### iv. Bystander Communication System

The bystander communication system **136**, which can be used to generate audible and/or visible cues for perception by people near a delivery location while the device **106** is raised and lowered. The various cues generated by the bystander communication module **136** are selected to facilitate safe, intuitive interactions between bystanders on the ground and a UAV delivery system.

The bystander communication system **136** can include one or more human interface modules configured to generate cues perceptible to people on the ground. For example, the bystander communication system **136** may include a light source and/or an audio source. The light source may include a lighting system that flashes or changes colors to indicate different states of the delivery system (e.g., one cue as the payload-release device **106** descends from the UAV **100**, and a second cue as the payload-release device **106** is retracted back to the UAV **100**). The light source may include one or more individual light emissive elements, such as light emissive diodes, and/or light transmissive elements, such as a liquid crystal device. For instance, the light source may include a display panel of emissive or transmissive elements on which scrolling text messages or pictures can be rendered. The audio source may include a loudspeaker that functions to output sound waves for perception by people on the ground. For instance, the loudspeaker may emit one audio cue during payload descent to provide a cue to bystanders and/or payload recipients that the payload is approaching the ground (e.g., a recording or synthesized voice saying "Please stand back as your package is being delivered" or another warning message), and another audio cue following payload delivery to

provide a cue that the delivery is complete (e.g., a recording or synthesized voice saying “You can now collect your package” or another message).

In addition to interface and/or communication capabilities performed by the bystander communication system **136**, the UAV delivery system may include back-end processes to facilitate communications with particular individuals who are payload recipients. For instance, the system may generate and send messages to payload recipients via various communication networks (e.g., cellular telecommunication networks, wide area networks, such as the Internet, etc.). In a particular example, a control system associated with the UAV delivery system may send a given intended payload recipient one or more communications via text messages, emails, etc., so as to inform the recipient of the progress of the delivery process. Such messages may include indications of: an estimated delivery time, an anticipated time until payload delivery, indications that the payload (or UAV bearing the payload) has departed for the delivery location, has reached a predetermined distance from the delivery location, has arrived at the delivery location, that the payload is descending toward the ground, and/or that delivery is now complete. In some cases, moreover, the system may allow for an intended recipient to send responsive communications to the UAV control system so as to effect a modification of one or more delivery parameters, including, without limitation, a delivery time, a delivery location, and/or other aspects of the delivery process. Additionally, the system may allow the intended recipient to accept, deny, and/or re-direct a given payload via communication with the control system. Other examples are also possible.

#### v. UAV Tracking Features

The payload-release device **106** can include features **140** that facilitate position tracking using the UAV **100**. For example, the payload-release device **106** may include one or more reflector(s) **142** and/or emitter(s) **144** situated on the payload-release device **106** so as to direct light toward the UAV **100** while the payload-release device **106** is suspended from the UAV **100** via the tether **102**. For instance, the reflector(s) **142** may include an arrangement of reflective surfaces mounted on a top surface of a housing of the payload-release device **106**. Similarly, the emitter(s) **144** may include one or more sources of radiation, such as light emissive diodes mounted to a top surface of the housing of the payload-release device **106**. The reflective surfaces **142** and/or emitters **144** can then be detected using an imaging system on the UAV **100** that is arranged to capture a field of view including the payload-release device **106** while the payload-release device **106** is suspended from the UAV **100** via the tether **102**. The imaging system on the UAV **100** can capture an image of the suspended payload-release device **106**. The image can then be used to identify a current location of the payload-release device **106** with respect to the field of view of the imaging system. In particular, the captured image can be analyzed to identify a location in the image that corresponds to the arrangement of reflectors **142** and/or emitters **144**. The identified location can then be mapped to a corresponding location of the suspended payload-release device **106**.

For instance, the imaging system on the UAV **100** may include a camera situated on a gimbal mount so as to have a substantially fixed downward-facing perspective of the region below the UAV **100**. During a delivery operation, such a camera can then be used to track the payload-release device **106** by identifying a region of a captured image that includes the reflector(s) **142** and/or emitter(s) **144**. The identified region or image coordinate in the captured image can then be mapped to a location of the payload-release device **106** based

on the current location and orientation of the UAV **100**, the orientation of the imaging system with respect to the UAV **100**, and the altitude difference between the UAV **100** and the payload-release device **106**.

The reflectors **142** and/or emitters **144** may be configured to assist in identifying the reflectors **142** and/or emitters **144** and in distinguishing them from background light sources. In some examples, the reflectors **142** and/or emitters **144** may be arranged in a pattern in which one or more of the reflectors **142** and/or emitters **144** are physically separated from one another. In some examples, the reflectors **142** and/or emitters **144** may reflect/emit light with different colors. In some examples, the reflectors **142** and/or emitters **144** may emit light at a particular wavelength and the imaging system may filter incoming light for that wavelength. For example, the emitter **144** may be an infrared LED or the reflector **142** may be configured to preferentially reflect infrared light (e.g., from infrared radiation emitted by the UAV **100**). Other examples are also possible in which the reflectors **142** and/or emitters **144** are arranged so as to provide a pattern of light that can be identified from image data captured by an imaging system on the UAV **100**.

In examples in which the tracking features **140** include two or more reflectors **142** and/or light sources **144**, the relative orientation of the features **140** can be used to determine an orientation of the payload-release device **106** (e.g., a degree of rotation about an axis defined by the tether **102**). For example, if the payload-release device **106** includes two LEDs, one on each side, and the two emit light in different colors (or are otherwise distinguishable via modulation, intensity, etc.), the location of the two emitters with respect to one another can be used to determine a degree of rotation of the payload-release device **106** about the tether **102**.

Furthermore, the observed separation between multiple emitters **144** (and/or reflectors **142**) can be used to estimate the altitude distance between the imaging system on the UAV **100** and the payload-release device. That is, for a given perspective ratio of the imaging system, emitters separated by a fixed amount appear closer together, as measured in image coordinates (e.g., pixels), when the emitters are distant from the imaging system, than when the emitters are closer to the imaging system. The system may therefore use separations measured in image coordinates to estimate a distance to the payload-release device **106**, and thus an altitude of the payload-release device **106**. Similarly, if the tracking system is informed of the altitude of the payload-release device **106** from another source (e.g., an altimeter on the payload-release device **106**), the imaging system may tune a pattern recognition routine and/or identification routine to scale a pattern of emitters being searched for within obtained image data.

In some examples, the upward-facing emitter **144** may emit light in a narrow wavelength range (e.g., a light emissive diode that emits at a narrow band of frequencies) and the imaging system on the UAV **100** may include a corresponding narrow band filter that passes the emitted light. The filter on the imaging system can thus preferentially select the light from the emitter **144** while decreasing interference from other light. The payload-release device **106** can thereby be identified within an image captured by the imaging system more readily than otherwise possible. In order to determine a position of the payload-release device **106** from the image data, an image coordinate at which the tracking features **140** are identified is mapped to a physical location based on a geometric relationship between the orientation of the imaging system field of view and the altitudes of the UAV **100** and the payload-release device **106**. In some examples, the imaging system may be mounted on a stabilizing mount, such as a three-

13

dimensional gimbal mount, so as to substantially fix an orientation of the imaging system with respect to the orientation of the UAV 100 and/or the ground. As such, a given image coordinate of a captured image obtained using the stabilized imaging system can be mapped to a line in the field of view of the imaging system that extends between the imaging system and the ground. Combining the direction information with information regarding the current altitude of the payload-release device 106 can then allow for determining the three-dimensional location of the payload-release device.

Moreover, because the imaging system is situated on the UAV 100, at a perspective so as to look down on the payload-release device 106 as it is suspended from the UAV 100 via the tether 102, the location information derived via the image tracking system may be useful in identifying the location of the payload-release device in a surface transverse to the direction of the tether 102. To the extent that the imaging system is arranged with a perspective that is close to a connection point between the tether 102 and the UAV 100 (e.g., near the tether-deployment mechanism 104), image coordinates of the imaging system can be mapped to locations of the payload-release device 106 on surfaces defined by fixed lengths of the tether 102. That is, for a given length of deployed tether, the payload-release device 106 can be constrained to move along a surface on which each point is the same distance from the tether attachment point on the UAV 100, and that distance is defined by the length of deployed tether. The different locations along that surface can each be mapped to a particular image coordinate in the field of view of the imaging system. Thus, the three-dimensional location of the payload-release device 106 with respect to the UAV 100 can be determined based on the length of deployed tether (or another indicator of the altitude of the payload-release device) and image coordinates at which the tracking features 140 are observed via the imaging system on the UAV 100. The accuracy of the determined location is then a function of the imaging resolution and the resolution of the altitude indicator.

#### vi. Position Sensors

The sensor(s) 150 can include one or more systems that generate data indicative of the altitude, position, and/or status of the payload-release device 106 and/or the payload 108. The sensor(s) 150 may include inertial motion sensor (IMU) 152 (e.g., accelerometers and/or gyroscopes) that function to generate data indicative of rotational and/or translational motion of the payload-release device 106. The sensor(s) 150 may additionally or alternatively include an altitude sensor 154, such as a barometric altimeter that functions to measure the local atmospheric pressure, which can be used to estimate the current altitude of the payload-release device 106. The sensor(s) 150 may additionally or alternatively include an active ranging system 156 such as a laser ranging system or radio ranging system that estimates the distance to the ground based on time of flight of reflected radiation transmitted by the payload-release device 106 and reflected from the ground. Similarly, such active ranging systems may function to estimate the distance to the UAV 100 from which the payload-release device 106 is suspended.

The sensor(s) 150 may additionally or alternatively include imaging system(s) that function to capture image data or video from a camera mounted on the payload-release device 106. The imaging system(s) may include, for example a pair of cameras that can be used to estimate the distance to the ground stereoscopically, for instance, by focusing the two spatially separated cameras on a common ground feature and determining distance based on the angle between the cameras. Other sensors may include proximity sensors and/or encoders that function to provide an indication of whether the

14

payload 108 is secured to the payload-release device 106. The sensor(s) 150 can function to generate sensor data indicative of the various parameters they are configured to measure, and the sensor data can then be provided to the UAV 100 (via the communication system 128) and/or to the processing system 120 on the UAV 100.

Moreover, in some examples, sensor data related to the position of the payload-release device 106 may be generated by, or in cooperation with, components on the UAV 100. For example, a position tracking system may include an upward-facing light source and/or reflector mounted on the payload-release device 106 (e.g., the tracking features 140), and a downward-facing imaging system mounted on the UAV 100. The imaging system can track the position of the suspended payload-release assembly 106 by tracking the location of the upward-facing light source and/or reflector in the field of view of the imaging system. The UAV 100 may also include other sensors that generate data related to the position of the payload-release device, such as an encoder that indicates a length the tether 102 deployed from the tether-deployment mechanism 104, and thus an altitude of the payload-release device, a line tension sensor that indicates a degree of tension on the tether 102 and thus whether the payload-release device 106 is resting on the ground, a thrust sensor that indicates an amount of thrust provided by the UAV's propulsion system and thus whether the payload-release device 106 is resting on the ground, and/or other sensors.

For example, the length of the tether 102 that has been let out by the tether-deployment mechanism 104 may be used to determine the distance between the payload 108 and the ground (i.e., the altitude of the payload 108). More specifically, given the height of the payload 108, the height of the payload-release device 106, the length of the tether 102, and the altitude difference between the top of the tether 102 and the point where altitude is measured by the UAV 100, the UAV 100 may determine the distance between the bottom of the payload 108 and the ground. Thus, the distance between the payload 108 and the ground can be updated as the line 102 is deployed, which may be indicated by readings from an encoder associated with the tether-deployment mechanism 104.

Data from the sensors 150 can then be used to estimate the altitude and/or position of the payload-release device 106 as it is lowered to the ground. For example, the accelerometer data and/or altimeter data can be used to determine how far the payload-release device 106 (and the payload 108) has been lowered using the tether 102, and thus how much distance remains to the ground. In addition, data from the accelerometer 152 may be used to detect a collision with the ground by the payload-release device 106 and/or the payload 108. Such a collision event may be indicated by the accelerometer data as an abrupt deceleration event with a characteristic signature, for example. In some examples, impact with the ground may be indicated by acceleration (as indicated by data from an accelerometer mounted in the payload-release device 106) with a magnitude that exceeds a threshold. Information from such sensors can then be communicated to the UAV 100 using the communication system 128. Moreover, the determination that the device 106 is at or near the ground may be based on one or more factors, including sensor data from position sensors on the device 106 (e.g., accelerometer and/or altimeter data), sensor data from sensors on the UAV 100 (e.g., encoder, image data, and/or tether tension data), and/or a communication from a remote control system (e.g., a remote operator may observe a video feed or other indicia and alert the UAV 100 when the device 106 is at or near the ground).



## 15

## vii. Translational Positioning System

The payload-release device **106** can include a translational positioning system **160**. The translational positioning system **160** can include thrusters **162** and/or air foils **164** that can be used to apply force on the payload-release device **106** while the payload-release device **106** is suspended from the UAV **100** via the tether **102**. The translational positioning system **160** uses one or more components to interact with the surrounding air to generate force on the payload-release device **106** and may be alternately referred to herein as an air propulsion system. The thruster **162** and/or air foil **164** can apply force on the payload-release device **106** in a direction that is at least partially transverse to the direction of the tether **102** as the payload-release device **106** is suspended from the UAV **100** via the tether **102**. For instance, the thruster **162** can include a turbine, fan, or other rotating blade mounted to the housing of the payload-release device **106**. The thruster **162** may also be situated within a shroud to both direct airflow and to protect the blade and other objects from interfering with moving parts of the thruster **162** (e.g., rotating blades). The airfoil **164** may include a wing or sail of rigid or flexible material that is mounted to the housing of the payload-release device **106** so as to apply force on the payload-release device **106** via interaction with air surrounding the payload-release device **106**.

For example, a pair of thrusters may be oriented to generate thrust transverse to one another and transverse to the tether **102**. Operating the thrusters **162** in respective directions can therefore cause the payload-release device **106** to move in a desired direction transverse to the direction of the tether **102**. Moreover, the payload-release device **106** can be moved along the direction of the tether **102** by reeling the tether **102** in and out (e.g., via the tether-deployment mechanism **104**). Thus, the payload-release device **106** can be moved along a desired three-dimensional path by manipulating both the tether-deployment mechanism **104** and the translational positioning system **160**.

In practice, the translational positioning system **160** may be used to adjust the location of the payload-release device **106** as it descends via the tether **102** according to position feedback information from the imaging system used to track the tracking features **140**, from the position sensors **150**, and/or from other sources. For example, the translational positioning system **160** may be used to cause the payload-release device **106** to descend along a particular path of descent associated with an intended delivery location. The path of descent may be, for example, a predicted path along which the payload-release device **106** will travel to the intended delivery location. The path of descent may be, for example, a straight line normal to the ground (e.g., in conditions with no wind or other atmospheric disturbances that apply force to the payload-release device other than gravity). The path of descent may also be, for example, a path that account for wind applying force on the suspended payload-release device **106** in a direction at least partially transverse to the direction of the tether **102**. A control system (e.g., on the UAV **100**) can be used to monitor the positioning information to detect a deviation from the predetermined path of descent. The control system can then cause the translational positioning system **160** to direct the descending payload-release device **106** toward the predetermined path of descent. Additionally or alternatively, the control system may adjust a position of the hovering UAV **100** to at least partially compensate for a detected deviation from the predetermined path of descent.

## 16

## viii. Payload Release System

The payload-release device **106** can also include a payload-release system **170**, which can include one or more electro-mechanical components that can be manipulated to alternately secure the payload **108** or release the payload **108**. The payload-release system **170** can include one or more actuator(s) **172** (e.g., a solenoid, motor, hydraulic component, etc.), grippers **176** (e.g., clamps, opposable arms, etc.), retaining rods or hooks **174**, or other components. The actuator **172** may be mechanically linked to the retaining rod **174** and/or gripping surface **176** to facilitate moving the rod **174** and/or gripper **176** between different positions in response to electronically generated signals (e.g., from the processing system **120**). For example, in one position, component(s) of the payload release system **170** can couple the payload-release device **106** to the payload **108**, and in another position, component(s) of the payload release system **170** can release the payload **108** from the payload-release device **106**.

The payload-release system **170** may secure the payload **108** to the payload-release device **106** in different ways. In some examples, grippers, fasteners, or other engaging surfaces function to secure the payload **108** (e.g., by applying pressure to the payload **108** or by engaging corresponding surfaces of the payload **108**). In some cases, the payload **108** may include one or more apertures or other standardized interfacing features configured to interface with the payload-release device **106**. Thus, the payload-release device **106** may include prongs or the like that interface with the payload **108** by passing through the payload's apertures (or otherwise engaging standardized features). The payload-release device **106** can also release the payload **108** by disengaging the grippers or engaging surfaces, or by detaching from the payload's standardized features.

In some cases, the retaining rod **174** may include a hook that is rotated between different positions via the actuator **172**. In one position, the rod **174** can engage an aperture of a payload mount attachment while the mount attachment is inserted within a channel formed in a housing of the payload-release device **106**. The mount attachment may be a substrate or other structure that extends from a top surface of the payload **108** and has an aperture formed therein for receiving the rod **174**. While lowering the payload **108** from the UAV **100**, the mount attachment can be inserted into the channel and the rod **174** can cross through the aperture (e.g., by crossing through the channel) so as to engage the payload **108**. The rod **174** can then be withdrawn from the channel to release the payload **108** from the payload-release device **106** once the payload **108** is on the ground.

Additionally or alternatively, the payload-release device **106** may include opposable arms. The opposable arms can be used to grip the payload **108** while lowering the payload **108** from the UAV **100**, and then can be separated to release the payload **108** once the payload **108** is on the ground. Additionally or alternatively, the payload-release device **106** may also take the form of a container, bucket, cage, or other enclosure with a bottom (or other enclosing surface) that can be opened and/or removed. While the payload **108** is lowered from the UAV **100**, the payload **108** can be secured within the enclosure, and then the bottom of the enclosure can be opened once payload **108** is on the ground. Additionally or alternatively, the payload-release device **106** may include one or more magnetic features, which may or may not be activated/deactivated in response to an input, such as permanent magnets, paramagnetic materials, electromagnets, etc. In such an example, the payload **108** may also include magnetic features, which may or may not be activated/deactivated in response to an input, and the payload **108** can be secured to



17

the payload-release device **106** via magnetic attractive forces between such magnetic features and then the payload **108** can be released by deactivating at least one of the magnetic features or by overcoming the attractive force. Additionally or alternatively, the payload-release device **106** may include an engaging rod or hook that engages a corresponding depression or aperture in the payload **108**. For example, the payload **108** may be formed to include one or more loops along its top or side surfaces. To secure the payload, the rod(s) or hook(s) of the payload-release device **106** can be maneuvered to engage such loops. Similarly, the payload can be released by manipulating the rod(s) or hook(s) to disengage the loops. In some examples, the rod, hook, or other payload-engaging mechanism may be implemented as: a coupling link with a portion that opens and closes, similar to a carabiner; a hook mounted below the payload-release device **106** (i.e., not mounted to pass within a channel); and/or a closed loop that engages a hook on the payload **108** and then translates and/or rotates to disengage from the hook during payload release. The payload-release device **106** may additionally or alternatively include other examples of devices, mechanisms, features, and systems may also be used to alternately engage a payload via a mechanical connection and, in response to determining it is time to release the payload, release the payload via manipulation of one or more components on the payload-release device **106** and/or payload **108**.

Various other types of payload-release systems are also possible. The form of a payload-release device for a particular implementation may depend on, for example, the types of payloads to be delivered and the environmental conditions in which delivery will be made. For example, the payload-release device **106** may be positioned on the tether **102** or at the top of the tether **102**, and may be operable to cut the tether or release the tether from the UAV **100** when the payload **108** is at or near the ground.

#### D. Control System

The UAV **100** may include or be associated with a control system configured to provide various functions described herein. The control system may include or take the form of program instructions stored in a non-transitory computer-readable medium and may also include a variety of functional modules implemented by software, firmware, and/or hardware. In some examples, the control systems described herein may include components located in the payload-release device **106**, in the UAV **100**, and/or at a remote location and in communication with the UAV **100**. However, the various components are configured to communicate information amongst one another to coordinate functioning of the UAV **100** and the payload-release device **106** such that determinations can be made and/or actions can be performed by one component on the basis of information obtained via other components communicatively linked to that component.

The control system may be configured to autonomously navigate the UAV **100** toward a specified destination. For example, the control system may determine a set of flight-command instructions that cause propulsion systems of the UAV **100** to operate such that the UAV flies through a set of waypoints that define a route to the specified destination. Among other factors, the control system may plan routes based on information from other aerial vehicles (or control systems therefore) and/or based on pre-determined guidance, regulations, and/or other constraints regarding allowable routes, altitudes and speeds in particular regions, etc. The control system may also be configured to operate the payload delivery system **110** to controllably lower the payload **108** to the ground, release the payload **108**, and then retract the payload-release device **106** back to the UAV **100**. Thus, the

18

control system can function to regulate the operation of a variety of actuators, servo controls, and other electromechanical devices that are involved in the operation of the payload delivery system **110**.

The control system of UAV **100** may also control the payload-release device **106** to release the payload **108** at or near the ground. For example, the control system may trigger the payload-release device **106** to release the payload **108** (e.g., by actuating the payload release system **170**) after a certain length of the tether **102** has been let out by the tether-deployment mechanism **104**, such that it is expected that the payload **108** is on the ground, or near enough to the ground that it can safely drop to the ground. The control system may also receive sensor data from an accelerometer on the payload-release device **106**, and determine that the payload **108** is on the ground when the accelerometer data indicates that the payload **108** had an impact with the ground followed by remaining at rest. Other examples are also possible in which the control system can function to determine that the payload **108** is at or near the ground and then responsively cause the payload-release device **106** to release the payload **108**.

In some cases, the control system can operate the payload delivery system **110** such that the rate of descent of the payload **108** is altitude dependent. For example, the control system can initially allow the payload **108** to descend at a maximum rate of descent. The control system can monitor information from sensors indicating the descending altitude of the payload **108**, and upon detecting that the payload **108** is within a particular distance of the ground, the control system can cause the tether-deployment mechanism **104** to begin slowing the descent of the payload **108**. The control system may cause the rate of descent to slow to a predetermined safe speed by the time the payload **108** is near enough to the ground that it could interfere with (or be grabbed by) objects or people on the ground. Similarly, the control system may also cause the payload-release device **106** to ascend back to the UAV **100** in an altitude-dependent manner after releasing the payload **108**.

#### E. Example Payloads

The payload **108** may be a standardized container or parcel that includes one or more features configured to interface with the payload-release device **106**. For instance, the payload **108** may include one or more loops, indentations, tabs, anchor points, or other structural features arranged to be engaged by corresponding components of the payload-release device **106** (e.g., the payload release system **170**). In some cases, the standardized features of the payload **108** may be integrated in a packaging module (e.g., a reusable or disposable container), and the packaging module may house (or be fastened to) one or more items that are being delivered using the UAV **100**. Such items may include food, medical equipment or supplies, retail goods, relief items, or any other items that may be delivered by a delivery service. In some cases, the delivered items may be supplied to stranded or isolated people in an emergency or rescue scenario. In some cases, the payload **108** may also include an identifying element to facilitate recognition and/or differentiation, of the payload **108** from other payloads when being sorted and handled. The identifying element may include an RFID tag or an optically scanned linear or two-dimensional barcode. The identifying element can then be associated with information regarding the particular payload in a database that can be accessed by various systems used in handling/sorting payloads, and in loading the UAV **100**. For example, such a database may associate the identifying element with contents of the payload, delivery destination, and/or other information pertaining to the particular payload and its delivery. Systems interfacing with a

given payload can then scan its identifying element and retrieve the information from the database that relates to the given payload.

In some examples, the payload **108** may take the form of a container that includes medical-support devices and/or other items intended to help in a medical situation. In other examples, the payload **108** may itself be a medical-support device (e.g., a defibrillator) or another type of medical support item, such as a pharmaceutical medicine. Generally, the payload **108** may include any type of item to be delivered, including non-medical items such as goods ordered from a non-medical delivery service or items shipped through a shipping service.

#### F. Emergency-Release System

In yet a further aspect, a UAV **100** may include an emergency-release system (not shown in the Figures), which is configured to cut or release the tether **102** from the UAV **100**. In particular, the UAV **100** may be configured to detect certain emergency situations, such as the tether **102**, payload-release device **106**, and/or payload **108** becoming stuck (e.g., in a tree or other obstacle), and to automatically cut the tether **102** when such an emergency situation is detected. The emergency situation may also involve the tether **102** and/or payload-release device **106** being grabbed by an individual on the ground. By cutting the tether **102** in such emergency situations, the UAV **100** can prevent damage to or from the UAV **100**, such as may occur in a scenario where the UAV **100** is pulled to the ground by an entangled tether **102**.

Various types of emergency-release mechanisms are possible. The emergency-release mechanisms may be configured to cut the tether **102** or otherwise release the tether **102** from the UAV **100**. In one example, the emergency-release mechanism may include a blade mounted on a cartridge that can be propelled through a firing cylinder by igniting a chemical explosive or propellant. The firing cylinder can be mounted on the UAV **100** near the tether-retraction mechanism **104** such that, when fired, the motion of the cartridge causes the blade to sever the tether **102** and thereby disconnects the unreeled tether **102** (and payload-release device **106**) from the UAV **100**.

Further, various types of data may be analyzed to determine if and when an emergency-release mechanism should be used to release the tether **102**. The control system can function to determine that such an emergency situation has occurred based on data from sensors on the UAV **100** and/or the payload-release device **106**. Indications of the emergency situation may be provided by the position sensors **150** in the payload-release device **106** and/or from sensors generating data indicative of a condition of the tether **102** (e.g., a line tension sensor). Further, the UAV's control system could analyze image data from a camera, data from a line-tension sensor, data from sensors monitoring thrust exerted by the UAV's propulsion systems, and/or other types of data to determine that the payload **108** and/or payload-release device **106** is stuck, has been interfered with, or that deployment of the payload **108** has otherwise failed. Upon determining that an emergency situation has occurred, the control system can responsively use the emergency-release mechanism to release the payload **108** and/or the payload-release device **106** (e.g., by severing the tether **102**). In some cases, the control system may receive an indication of the emergency situation from a remote terminal where a supervisory control operator is monitoring sensor data and has determined that the tether **102** should be cut (e.g., based on analyzing a video feed from imaging system(s) associated with the UAV **100**).

#### G. Other Aspects

In some examples, the UAV **100** may include features that can hold the payload **108** in place and/or stabilize the payload during flight. Such features may be mechanically adjustable such that the tether-deployment mechanism **104** can lower the payload **108** upon arriving at the delivery location. For instance, in the configuration shown in FIG. **1A**, UAV **100** includes moveable retaining brackets **114**. The brackets **114** may interface with the payload **108** and/or device **106** to hold the payload **108** in place during flight, as shown in FIG. **1A**. And when UAV **100** reaches the delivery location, the brackets **114** may be moved away from payload **108**, so that the payload **108** can be lowered without interference from the brackets **114**. Note that other types of mechanisms may also be used to hold the payload **108** in place and/or to stabilize the payload **108** during flight. Moreover, the payload **108** may be held in place during flight by the device **106**, without use of any additional features.

Further, in some implementations, the payload delivery system **110** may omit the payload-release device **106**. For example, the payload itself may incorporate a rolling mechanism that traverses the tether **102** and simply rolls off the end of the tether **102** upon reaching the end, thereby releasing the payload **108** from the UAV **100**.

In some examples, a UAV **100** may additionally or alternatively be configured to pick up items from the ground using the payload delivery system **110** shown in FIGS. **1A-1D**, or a different type of system.

### III. EXAMPLE PAYLOAD-RELEASE DEVICE

FIG. **2A** is an aspect view of an example payload-release device **200**. The payload-release device **200** may include some or all of the functionality of the payload-release device **106** described in connection with FIGS. **1A-1D**. The payload-release device **200** includes a housing **210**, which may take a variety of forms. In some examples, the housing **210** may be an enclosure formed of a rigid material such as metal and/or plastic. The housing **210** may have surfaces designed to help prevent the device from becoming stuck or entangled while being lowered or raised by the tether. For example, the housing **210** may have a generally cubic or cuboid shape with rounded or partially rounded corners and/or edges between sidewalls. Many other shapes are possible.

The housing **210** can include a bottom surface **212** that includes a channel **220**. The bottom surface **212** may be a surface configured to be faced against a payload while the payload-release device **200** is secured to the payload. Thus, the bottom surface **212** may be generally flat (i.e., planar) or may be another surface that is configured to mate against a surface of a payload. The channel **220** may be integrally formed in the bottom surface **212**, or may be a cutout region of the bottom surface **212**. The channel **220** includes sidewalls **222**, **224**, which have a separation that defines a width of the channel **220**. The sidewalls **222**, **224** may be approximately transverse to the bottom surface **212** and the sidewalls **222**, **224** may optionally be connected to one another by respective end walls that define a length of the channel **220** transverse to its width. The sidewalls **222**, **224** may also have a non-constant separation distance throughout the depth of the channel **220**. For example, near the bottom surface **212**, the sidewalls **222**, **224** may be separated by a greater distance than further within the channel **220**. Moreover, the sidewalls **222**, **224** may be angled so as to become gradually closer to one another, at greater depths within the channel **220**. As such, a payload mount attachment inserted into the channel

21

220 (e.g., the attachment 240 in FIG. 2B) can be at least partially aligned and/or guided into the channel by the sidewalls 222, 224.

A retaining hook 230 is shown in an engaged position in FIG. 2A. The retaining hook 230 crosses the channel 220. The retaining hook 230 can pass through respective entry locations in the sidewalls 222, 224 to cross the width of the channel 220. As described below, while in the engaged position, a payload mount attachment inserted into the channel 220 can be secured by the retaining hook 230. The retaining hook 230 can also be withdrawn from the channel 220, which allows a payload mount attachment to exit the channel 220 without interference. Thus, the retaining hook 230 can be positioned to alternately: (i) engage a payload mount attachment inserted in the channel 220 and thereby secure the payload to the payload-release device 200, and (ii) release a payload mount attachment from the channel 220 and thereby release the payload from the payload-release device 200.

FIG. 2B is a side view of the example payload-release device 200 aligned to engage a payload 248. FIG. 2C is a side view of the example payload-release device 200 secured to the payload 248. The payload 248 includes a top surface 246. The top surface 246 of the payload 248 may be a generally flat surface, or another surface that is configured to interface with the bottom surface 212 of the payload-release device housing 210. A payload mount attachment 240 is situated on the top surface 246. The payload mount attachment 240 is configured to be received within the channel 220 and be engaged by the retaining hook 230. The payload mount attachment 240 can include a structure 242 that extends approximately transverse to the top surface 246. An aperture 244 in the structure 242 can then receive the retaining hook 230 while the structure 242 is inserted into the channel 220, which is shown in FIG. 2C. In particular, the retaining hook 230 can make contact with a rim of the aperture 244, which contact can mechanically couple the payload-release device 200 to the payload mount attachment 240 (and thus the payload 248). The structure 242 may be, for example a substrate such as a polymeric and/or fiber-based substrate. In some instances, the structure 242 may be a cardboard structure that extends from a cardboard packaging enclosure for the payload 248.

FIGS. 2D and 2E are side cross-sectional views of the payload-release device 200 retaining hook 230 in an engaged position and in a disengaged position. The depth of the channel 220 extends to an end wall 226, which can connect the sidewalls 222, 224. The retaining hook 230 can include an engagement surface 236 that extends between an elbow 234 and an end 232. The retaining hook 230 can enter the channel through entry locations 223, 225, which can be formed in the sidewalls 222, 224 to allow insertion of the retaining hook 230 into the channel 220. The entry locations 223, 225 can also be seen in FIG. 2A. In the engaged position, which is shown in FIG. 2D, the engagement surface 236 of the retaining hook 230 crosses between the two sidewalls 222, 224 of the channel 220. As a result, if a structure is inserted into the channel 220, the structure is enclosed by the engagement surface 236, the end wall 226, and the sidewalls 222, 224. In the disengaged position, which is shown in FIG. 2E, the retaining hook 230 is withdrawn from the channel 220 entirely. In particular, the engagement surface 236 does not cross the sidewalls 222, 224, and as a result a structure inserted in the channel 220 is not prevented from exiting the channel 220. While the disengaged position shown in FIG. 2D illustrates the retaining hook 230 entirely withdrawn from the channel 220 (i.e., the end 232 is outside the entry location 225), some examples may involve a portion of the retaining hook 230 situated within the channel 230 during disengage-

22

ment (e.g., the end 232 passing through the entry location 225, but not entry location 223).

The retaining hook 230 is mounted within the housing 210 on an axle 238 so as to rotate about an axis defined by the axle 238. The axle can be oriented transverse to the width of the channel 220 such that rotating the retaining hook 230 causes the engagement surface 236 to move into and out of the channel 220. The axle 238 can be positioned within the housing 210 at a depth greater than the depth of the channel 220, and approximately centered with respect to planes defined by the two sidewalls 222, 224. Other configurations are possible. For instance, the axle may be located at a different location and/or orientation within the housing 210, and the retaining hook may take a different form so as to effect insertion and withdrawal of the retaining hook 230 in response to rotary actuation of the retaining hook with respect to the axle. Moreover, the retaining hook 230 may be implemented by a rod (or another structure) that is actuated by a linear actuator, rotary actuator, stepper motor, hydraulic system, etc. so as to alternately insert and withdraw the rod to and from the channel.

The retaining hook 230 and/or the payload mount attachment 240 can be formed of a rigid or semi-rigid material such as metal, plastic, composite, and/or paper-based substrates. The retaining hook 230 can be designed to have sufficient tensile strength to secure the payload 248 via the payload mount attachment 240 while the payload undergoes accelerations expected during a delivery and/or flight operations, for example.

FIG. 2F is a top view of the example payload-release device 200. The top surface 214 of the housing can include a tether anchor 260. The tether anchor 260 can be an attachment point for coupling a tether to the payload-release device 200. The tether anchor 260 may include, for example, a pair of apertures 262, 264 and the tether can be coupled thereto by inserting the tether into one of the apertures 262, 264 and bringing it out of the other. Once threaded through the tether anchor 260, the tether may be coupled to itself using a clamp, knot, or another technique. The tether anchor 260 may be reinforced by an internal and/or external structure of the housing 210 in some examples to allow the tether anchor 260 to transmit forces from the tether exerted on the payload-release device and/or payload. Moreover, in some cases payload-release devices may include alternate tether anchor implementations and/or alternative physical features configured to couple the housing to a tether that is suspended from a UAV. For instance, some examples may include a tether anchor configured as a hook that receives a loop in a tether suspended from a UAV, one or more clamps that squeeze a suspended tether, a winch device that can be used to wind/unwind a portion of a suspended tether coiled around an axle of the winch device. Many other examples of tether anchors are also possible.

The top surface 214 can also include a first light emitting diode (LED) 250 and a second LED 252. The LEDs 250, 252 can be used to track the position of the payload-release device 200 while it is suspended from the UAV, for example using an imaging system on the UAV. In some cases, the LEDs 250, 252 can emit light in different colors (e.g., one red, one green) to facilitate distinguishing the pair of LEDs 250, 252 from background light sources. In some cases, the LEDs 252, 254 may be distinguishable from one another by one or more other factors, such as intensity, modulation pattern, etc. The LEDs 252, 254 may also be arranged on the top surface 214 in a manner that is rotation invariant. As a result, the positions of the two LEDs 252, 254, as observed via an imaging system on a hovering UAV, can be used to determine an orientation of the payload-release device 200.

## IV. EXAMPLE OPERATIONS

FIGS. 3A and 3B are flow charts illustrating processes that may be performed by a payload delivery system in connection with a delivery operation. FIG. 3A is a flowchart of an example process 300 that can be performed by a payload delivery system during a delivery operation. In particular, the process 300 involves using a payload-release device to lower a payload to a delivery location, and then releasing the payload by actuating a retaining rod once the payload is at or near the ground. The process 300 may be performed using either of the payload delivery systems described in connection with FIGS. 1A-2F.

At block 302, a payload delivery system is used to lower a payload from a hovering UAV. For example, the UAV may be hovering at a target location above a delivery location on the ground. The UAV can then use its retractable delivery system to lower the payload-release device, and the payload secured thereby, such as by unreeling the tether from a winch on the UAV. The payload-release device can include a retaining rod that can be alternately positioned in an engaged position, in which the retaining rod engages the payload, and a disengaged position, in which the retaining rod does not interfere with the payload as it is released.

At block 304, the retaining rod is positioned in the engaged position as the payload-release device (and the payload secured thereby) descend from the UAV. Thus, the payload is secured to the payload-release device as the payload descends toward the ground. For example, an actuator in the payload-release device may be operated to hold the retaining rod in the engaged position such that a surface of the retaining rod contacts a surface of the payload mount attachment. While in the engaged position, contact between the retaining rod and the payload mount attachment can mechanically couple the payload and the payload-release device.

At block 306, the payload is determined to be at or near the ground. The determination may be made by a computing control system on the payload-release assembly and/or the UAV (or associated with the UAV). The determination may be based, at least in part, on sensor data from sensors on the payload-release device. For example, data from inertial motion sensor(s) included in the payload-release device can be analyzed to determine whether such data indicates that the payload and/or payload-release assembly underwent an impact with the ground. Upon detecting an acceleration sequence characteristic of a ground impact, the computing system(s) can determine that the payload is at or near the ground. Additionally or alternatively, the determination may be made in part based on altimeter sensor data, imaging data, tether reel encoder data, tether-tension sensor data, and/or UAV thrust sensor data. The tether-tension sensor data and/or UAV thrust sensor data can be used, for example, to determine the amount of weight suspended from the UAV by the tether. A sudden decrease in the amount of suspended weight may thus indicate that the payload is on the ground. Other techniques for detecting that the payload is at or near the ground are described above in connection with FIGS. 1A-1D.

At block 308, the retaining rod can be moved from the engaged position to the disengaged position to thereby release the payload from the payload-release device. Moving the retaining rod may involve operating an actuator (e.g., a rotary or linear actuator, a solenoid, a hydraulic system, etc.) to withdraw the retaining rod from a channel of the payload-release device, as described in connection with FIGS. 2A-2F. In the disengaged position, the retaining rod may be entirely withdrawn from the channel or may be positioned such that the rod does not intersect a plane defined by at least one of the

sidewalls of the channel. As a result, the payload mount attachment associated with the payload is not prevented from exiting the channel in the payload-release device. The payload mount attachment can thus exit the channel under force of gravity, or may be ejected from the channel by a spring bias or actuator. Moving the retaining rod to the disengaged position allows the payload mount attachment to disengage from the payload-release device, and releases the payload from the payload-release device.

At block 310, the payload-release device is retracted back to the UAV. For example, a tether-deployment mechanism, such as a winch or ratchet, can be operated to reel in the tether. The released payload remains on the ground, at the delivery location, as the payload-release device is retracted back to the UAV.

FIG. 3B is a flowchart of an example process 320 that can be performed by a payload delivery system during a delivery operation. In particular, the process 320 involves determining that a payload is at or near the ground based on sensor data obtained from one or more position sensors situated in the payload-release device lowered with the payload. The process 320 may be performed using either of the payload delivery systems described in connection with FIGS. 1A-2F.

At block 322, a payload delivery system is used to lower a payload from a hovering UAV. For example, the UAV may be hovering at a target location above a delivery location on the ground. The UAV can then use its retractable delivery system to lower the payload-release device, and the payload secured thereby, such as by unreeling the tether from a winch on the UAV. The payload-release device can include a retaining rod that can be alternately positioned in an engaged position, in which the retaining rod engages the payload, and a disengaged position, in which the retaining rod does not interfere with the payload as it is released.

At block 324, payload-release device is secured to the payload as the payload-release device (and the payload secured thereby) descends from the UAV. The payload-release device may therefore include an electromechanical component that can be alternately positioned in an engaged position, in which the component engages the payload so as to mechanically couple to the payload, and a disengaged position, in which the component does not prevent the payload from being released from the payload-release device. The payload-release device securing the payload may involve positioning a retaining rod so as to engage an aperture in a payload mount attachment, for example. Thus, the retaining rod may engage the payload through a payload mount attachment of the payload (e.g., a structure with an aperture that enters a channel in the payload-release device). As such, in the disengaged position, the retaining rod does not engage the payload mount attachment.

At block 326, sensor data can be obtained from position sensors on the payload-release device. For example, an altimeter, accelerometer, gyroscope, and/or active ranging system situated on the payload-release device can generate sensor data related to the position of the payload-release device as it descends from the UAV. The generated sensor data can then be accessed by a control system on the payload-release device and/or communicated to a control system on the UAV.

At block 328, the payload can be determined to be at or near the ground based on the obtained sensor data. The sensor data may be analyzed according to various factors to identify indicator(s) that the payload-release device is at or near the ground. In some examples, the determination can involve a three step process performed by a control system with access to the sensor data.

25

First, at block 330, the control system can determine whether the payload-release device is within a threshold distance of the ground. If so, at block 332, the control system whether an acceleration of the device exceeds a threshold. If so, at block 334, the control system can determine whether the payload-release device is not in motion. If, at block 334, the control system determines that the payload-release device is at rest, then the control system determines that the payload-release device is on the ground and the process 320 proceeds to block 336. If, the three-stage process results in a determination that the payload-release device is not at or near the ground, the process 320 can continue to obtain sensor data, at block 326, and repeat the determination sequence, at block 328.

In practice, the three-stage determination shown in block 330, 332, and 334 can cause the control system to initially analyze altitude-indicative data (e.g., from an altimeter, ranging system, and/or IMU on the payload-release device). Once the altitude-related data indicates that the payload-release device is within a threshold distance of the ground, at block 330, the control system can analyze accelerometer data for an indication of a threshold-exceeding instantaneous acceleration, at block 332, which may indicate a ground impact. Finally, at block 334, the control system can analyze accelerometer and/or other data streams to determine whether the payload-release device continues to move after the threshold-exceeding acceleration, at block 334. If so, the control system may determine the payload-release device is not on the ground (e.g., such as may occur if the payload-release device initially strikes an obstacle, which produces a threshold-exceeding instantaneous acceleration, before reaching the ground). In practice, the determination of block 334 may involve evaluating sensor data from an accelerometer on the payload-release device and determining whether the instantaneous acceleration of the payload-release device is less than a second threshold value during an interval subsequent to detecting the threshold-exceeding acceleration of block 332. As used herein, instantaneous acceleration refers to an acceleration of the delivery device during a measurement interval, as indicated by sensor-generated data during that measurement interval. Thus, the various instantaneous acceleration values described herein may refer to values that represent the degree of acceleration of the delivery device from moment to moment during the delivery process, and each such value may be based on one or more raw sensor measurements (e.g., from an accelerometer) during an associated measurement interval. The second threshold may be less than the threshold for detecting ground impacts, and may correspond to an acceleration measurement expected while the device is at rest. For instance, the second threshold may be approximately zero. If, at block 334, the control system determines the payload-release device is at rest, the control system can determine the payload-release device is resting on the ground. The sensor data and sources of that data described in connection with blocks 330, 332, and 334 are provided for example purposes only. In some examples, additional or alternative sources of position-related sensor data may be used.

At block 336, the payload can be released from the payload-release device. Releasing the payload may involve actuating an electromechanical component so as to move the component from a position in which the payload is engaged to a position in which the payload is not mechanically linked to the payload-release device. For instance, releasing the payload may involve moving a retaining rod from the engaged position to the disengaged position to thereby release the payload from the payload-release device.

26

At block 338, the payload-release device is retracted back to the UAV. For example, a tether-deployment mechanism, such as a winch or ratchet, can be actuated to reel in the tether. The released payload remains on the ground, at the delivery location, as the payload-release device is retracted back to the UAV.

In practice, one or more of the operations described in connection with the processes 300 and 320 may be omitted or performed in a different order. Various combinations and/or variations of the processes 300 and 320 are therefore possible, and are included within the presently disclosed subject matter.

## V. ALTERNATE PAYLOAD RELEASE SYSTEMS

FIGS. 4A, 4B, 4C, 4D, 4E, and 4F illustrate alternate payload-release device configurations in engaged and disengaged positions. FIGS. 4A and 4B illustrate a payload-release device with a retaining hook 406 that alternately engages a payload mount attachment 410 inserted in a channel 404 (FIG. 4A), and releases the payload mount attachment 410 (FIG. 4B). FIGS. 4C and 4D illustrate a payload-release device with a retaining rod 416 that alternately engages a payload mount attachment 420 inserted in a channel 414 (FIG. 4C) and releases the payload mount attachment 420 (FIG. 4D). FIGS. 4E and 4F illustrate a payload-release device with a retaining rod 426 that moves along a bottom surface 422 of the payload-release device. The retaining rod 426 alternately engages a payload mount attachment 430 inserted in a channel 424 (FIG. 4E) and releases the payload mount attachment 430 (FIG. 4F).

In FIGS. 4A and 4B, the payload mount attachment 410 is inserted into the channel 404 in a bottom surface 402 of a payload-release device. The retaining hook 406 is mounted within the payload-release device to rotate about an axis 409. In the engaged position (FIG. 4A), the retaining hook 406 is within the channel 404 and an engagement surface 407 of the retaining hook 406 makes contact with the payload mount attachment 410 inserted in the channel 404. In a disengaged position (FIG. 4B), the retaining hook 406 is rotated about the axis 409 so as to exit the channel 404 via the entry locations 405a, 405b. In particular, in the disengaged position, the retaining hook 406 does not intersect either of the planes 408a, 408b defined by the opposing sidewalls of the channel 404. In some examples, the disengaged position may involve moving the retaining hook 406 to a location where it still intersects one of the planes 408a, 408b (e.g., the plane 408b), but is withdrawn enough from the channel 404 so as to not interfere with the payload mount attachment 410 exiting the channel 404 (e.g., under the force of gravity as indicated by the arrow).

In FIGS. 4C and 4D, the payload mount attachment 420 is inserted into the channel 414 in a bottom surface 412 of a payload-release device. The retaining rod 416 is mounted within the payload-release device to move in and out of the channel 414. The retaining rod 416 may be mechanically coupled to linear actuator (or another actuator) that applies force to the retaining rod in a direction transverse to the depth of the channel 414 such that the retaining rod 416 can move through the entry locations 415a, 415b in and out of the channel 416. In the engaged position (FIG. 4C), the retaining rod 416 is within the channel 414 and an engagement surface 417 of the retaining rod 416 makes contact with the payload mount attachment 420 inserted in the channel 414. In a disengaged position (FIG. 4D), the retaining rod 416 is moved along the interior surface of the housing so as to exit the channel 414 via the entry locations 415a, 415b. In particular,

27

in the disengaged position, the retaining rod **416** does not intersect either of the planes **418a**, **418b** defined by the opposing sidewalls of the channel **414**. In some examples, the disengaged position may involve moving the retaining rod **416** to a location where it still intersects one of the planes **418a**, **418b** (e.g., the plane **418b**), but is withdrawn enough from the channel **414** so as to not interfere with the payload mount attachment **420** exiting the channel **414** (e.g., under the force of gravity as indicated by the arrow).

In FIGS. **4E** and **4F**, the payload mount attachment **430** is inserted into the channel **424** in a bottom surface **422** of a payload-release device. The retaining rod **426** is mounted within the payload-release device to move along the bottom surface **422** of the payload-release device. The retaining rod **426** may be mechanically coupled to linear actuator (or another actuator) that applies force to the retaining rod in a direction transverse to the depth of the channel **424** (and parallel to the bottom surface **422**) such that the retaining rod **426** can move to overlap the channel **424** and away from the channel **424**. In the engaged position (FIG. **4E**), the retaining rod **426** overlaps the channel **424** and an engagement surface **427** of the retaining rod **426** makes contact with the payload mount attachment **430** inserted in the channel **424**. In a disengaged position (FIG. **4F**), the retaining rod **426** is moved along the bottom surface **422** of the housing, away from the channel **424**. In particular, in the disengaged position, the retaining rod **426** does not intersect either of the planes **428a**, **428b** defined by the opposing sidewalls of the channel **424**. In some examples, the disengaged position may involve moving the retaining rod **426** to a location where it still intersects one of the planes **428a**, **428b** (e.g., the plane **428b**), but is withdrawn enough from the channel **424** so as to not interfere with the payload mount attachment **430** exiting the channel **424** (e.g., under the force of gravity).

FIGS. **5A**, **5B**, **5C**, and **5D** illustrate alternate payload mount attachment configurations. Each of the payload mount attachments described herein may be formed of a rigid or semi-rigid material, such as metal, plastic, composite materials, and/or paper-based substrates.

In FIG. **5A**, a payload mount attachment **510** situated on a top surface of a payload **508**. The payload mount attachment **510** can include a structure **512** that extends from the top surface of the payload **508**. The structure **512** can have an aperture **516** for receiving a retaining rod while the structure **512** is inserted into a channel of a payload-release device. The aperture **516** may be roughly triangular, as shown in FIG. **5A**, which may help in accounting for alignment offsets with the retaining rod when the retaining rod engages the payload mount attachment **510**. The aperture **516** can have a rim **518**, which can make contact with the retaining rod while the payload mount attachment **510** is engaged by a retaining rod. The point of contact along the rim **518** may be, for example, the location along the rim that is furthest from the top surface of the payload **508** (e.g., the apex of the triangular aperture **516**), because the payload **508** will naturally move to that position once suspended by the retaining rod. The distance between the rim **518** and a top surface **514** of the structure **512** can therefore define a thickness of the structure **512** that is engaged between the retaining rod and an inner surface of a channel while the payload mount attachment **510** is engaged.

In FIG. **5B**, another payload mount attachment **520** is situated on a top surface of the payload **508**. The payload mount attachment **520** can include a structure **522** that extends from the top surface of the payload **508**. The structure **522** can have a circular aperture **526** for receiving a retaining rod while the structure **522** is inserted into a channel of a payload-release device. The aperture **526** can have a rim **528**, which can make

28

contact with the retaining rod while the payload mount attachment **520** is engaged by a retaining rod. The point of contact along the rim **528** may be, for example, the location along the rim that is furthest from the top surface of the payload **508**, because the payload **508** will naturally move to that position once suspended by the retaining rod. The distance between the rim **528** and a top surface **524** of the structure **522** can therefore define a thickness of the structure **522** that is engaged between the retaining rod and an inner surface of a channel while the payload mount attachment **520** is engaged.

In FIG. **5C**, another payload mount attachment **530** is situated on a top surface of the payload **508**. The payload mount attachment **530** can include a structure **532** that extends from the top surface of the payload **508**. The structure **532** can be a length of material anchored at both ends to the top surface of the payload **508**, such as a length of rope, wire, plastic, etc. Between the anchored ends, the structure **532** can encompass an area **536** for receiving a retaining rod while the structure **532** is inserted into a channel of a payload-release device. The area **536** can have a rim **538**, which can make contact with the retaining rod while the payload mount attachment **530** is engaged by a retaining rod. The point of contact along the rim **538** may be, for example, the location along the rim that is furthest from the top surface of the payload **508**, because the payload **508** will naturally move to that position once suspended by the retaining rod. The distance between the rim **538** and a top surface **534** of the structure **532** can therefore define a thickness of the structure **532** that is engaged between the retaining rod and an inner surface of a channel while the payload mount attachment **530** is engaged.

In FIG. **5D**, another payload mount attachment **540** is situated on a top surface of the payload **508**. The payload mount attachment **540** can include a hook structure **542** that extends from the top surface of the payload **508**. The hook structure **542** can have an interior channel **546** that includes an opening **549** through a side edge of the hook structure **542**. The interior channel **546** can be configured for receiving a retaining rod while the hook structure **542** is inserted into a channel of a payload-release device. The channel **546** can have a rim **548**, which can make contact with the retaining rod while the payload mount attachment **540** is engaged by a retaining rod. The point of contact along the rim **548** may be, for example, the location along the rim that is furthest from the top surface of the payload **508**, because the payload **508** will naturally move to that position once suspended by the retaining rod. The distance between the rim **548** and a top surface **544** of the hook structure **542** can therefore define a thickness of the hook structure **542** that is engaged between the retaining rod and an inner surface of a channel while the payload mount attachment **540** is engaged.

## VI. EXAMPLE UAVS

FIGS. **6A**, **6B**, **6C**, and **6D** are simplified illustrations of example unmanned aerial vehicles, according to example embodiments. Herein, the terms “unmanned aerial vehicle” and “UAV” refer to any autonomous or semi-autonomous vehicle that is capable of performing some functions without a physically-present human pilot. Examples of flight-related functions may include, but are not limited to, sensing its environment or operating in the air without a need for input from an operator, among others.

A UAV may be autonomous or semi-autonomous. For instance, some functions could be controlled by a remote human operator, while other functions are carried out autonomously. Further, a UAV may be configured to allow a remote

operator to take over functions that can otherwise be controlled autonomously by the UAV. Yet further, a given type of function may be controlled remotely at one level of abstraction and performed autonomously at another level of abstraction. For example, a remote operator could control high level navigation decisions for a UAV, such as by specifying that the UAV should travel from one location to another (e.g., from the city hall in Palo Alto to the city hall in San Francisco), while the UAV's navigation system autonomously controls more fine-grained navigation decisions, such as the specific route to take between the two locations, specific flight controls to achieve the route and avoid obstacles while navigating the route, and so on. Other examples are also possible.

A UAV can be of various forms. For example, a UAV may take the form of a rotorcraft such as a helicopter or multicopter, a fixed-wing aircraft, a jet aircraft, a ducted fan aircraft, a lighter-than-air dirigible such as a blimp or steerable balloon, a tail-sitter aircraft, a glider aircraft, and/or an ornithopter, among other possibilities. Further, the terms "drone", "unmanned aerial vehicle system" ("UAVS"), or "unmanned aerial system" ("UAS") may also be used to refer to a UAV.

FIG. 6A is a simplified illustration of a UAV 600, according to an example embodiment. In particular, FIG. 6A shows an example of a rotorcraft 600 that is commonly referred to as a multicopter. Multicopter 600 may also be referred to as a quadcopter, as it includes four rotors 602. It should be understood that example embodiments may involve rotorcraft with more or less rotors than multicopter 600. For example, a helicopter typically has two rotors. Other examples with three or more rotors are possible as well. Herein, the term "multicopter" refers to any rotorcraft having more than two rotors, and the term "helicopter" refers to rotorcraft having two rotors.

Referring to multicopter 600 in greater detail, the four rotors 602 provide propulsion and maneuverability for the multicopter 600. More specifically, each rotor 602 includes blades that are attached to a motor 604. Configured as such the rotors may allow the multicopter 600 to take off and land vertically, to maneuver in any direction, and/or to hover. Furthermore, the pitch of the blades may be adjusted as a group and/or differentially, and may allow a multicopter 602 to perform three-dimensional aerial maneuvers such as an upside-down hover, a continuous tail-down "tic-toc," loops, loops with pirouettes, stall-turns with pirouette, knife-edge, immelman, slapper, and traveling flips, among others. When the pitch of all blades is adjusted to perform such aerial maneuvering, this may be referred to as adjusting the "collective pitch" of the multicopter 600. Blade-pitch adjustment may be particularly useful for rotorcraft with substantial inertia in the rotors and/or drive train, but is not limited to such rotorcraft.

Additionally or alternatively, multicopter 600 may propel and maneuver itself adjust the rotation rate of the motors, collectively or differentially. This technique may be particularly useful for small electric rotorcraft with low inertia in the motors and/or rotor system, but is not limited to such rotorcraft.

Multicopter 600 also includes a central enclosure 606 with a hinged lid 608. The central enclosure may house, for example, control electronics such as an inertial measurement unit (IMU) and/or an electronic speed controller, batteries, other sensors, and/or a payload, among other possibilities.

The illustrative multicopter 600 also includes landing gear 610 to assist with controlled take-offs and landings. In other embodiments, multicopters and other types of UAVs without landing gear are also possible.

In a further aspect, multicopter 600 includes rotor protectors 612. Such rotor protectors 612 can serve multiple purposes, such as protecting the rotors 602 from damage if the multicopter 600 strays too close to an object, protecting the multicopter 600 structure from damage, and protecting nearby objects from being damaged by the rotors 602. It should be understood that in other embodiments, multicopters and other types of UAVs without rotor protectors are also possible. Further, rotor protectors of different shapes, sizes, and function are possible, without departing from the scope of the invention.

A multicopter 600 may control the direction and/or speed of its movement by controlling its pitch, roll, yaw, and/or altitude. To do so, multicopter 600 may increase or decrease the speeds at which the rotors 602 spin. For example, by maintaining a constant speed of three rotors 602 and decreasing the speed of a fourth rotor, the multicopter 600 can roll right, roll left, pitch forward, or pitch backward, depending upon which motor has its speed decreased. Specifically, the multicopter may roll in the direction of the motor with the decreased speed. As another example, increasing or decreasing the speed of all rotors 602 simultaneously can result in the multicopter 600 increasing or decreasing its altitude, respectively. As yet another example, increasing or decreasing the speed of rotors 602 that are turning in the same direction can result in the multicopter 600 performing a yaw-left or yaw-right movement. These are but a few examples of the different types of movement that can be accomplished by independently or collectively adjusting the RPM and/or the direction that rotors 602 are spinning.

FIG. 6B is a simplified illustration of a UAV 620, according to an example embodiment. In particular, FIG. 6B shows an example of a tail-sitter UAV 620. In the illustrated example, the tail-sitter UAV 620 has fixed wings 622 to provide lift and allow the UAV to glide horizontally (e.g., along the x-axis, in a position that is approximately perpendicular to the position shown in FIG. 6B). However, the fixed wings 622 also allow the tail-sitter UAV 620 take off and land vertically on its own.

For example, at a launch site, tail-sitter UAV 620 may be positioned vertically (as shown) with fins 624 and/or wings 622 resting on the ground and stabilizing the UAV 620 in the vertical position. The tail-sitter UAV 620 may then take off by operating propellers 626 to generate the upward thrust (e.g., a thrust that is generally along the y-axis). Once at a suitable altitude, the tail-sitter UAV 620 may use its flaps 628 to reorient itself in a horizontal position, such that the fuselage 630 is closer to being aligned with the x-axis than the y-axis (e.g., aligned parallel to the ground). Positioned horizontally, the propellers 626 may provide forward thrust so that the tail-sitter UAV 620 can fly in a similar manner as a typical airplane.

Variations on the illustrated tail-sitter UAV 620 are possible. For instance, tail-sitters UAVs with more or less propellers, or that utilize a ducted fan or multiple ducted fans, are also possible. Further, different wing configurations with more wings (e.g., an "x-wing" configuration with four wings), with less wings, or even with no wings, are also possible. More generally, it should be understood that other types of tail-sitter UAVs and variations on the illustrated tail-sitter UAV 620 are also possible.

As noted above, some embodiments may involve other types of UAVs, in addition or in the alternative to multicopters. For instance, FIGS. 6C and 6D are simplified illustrations of other types of UAVs, according to example embodiments.

In particular, FIG. 6C shows an example of a fixed-wing aircraft 640, which may also be referred to as an airplane, an



31

aeroplane, or simply a plane. A fixed-wing aircraft **640**, as the name implies, has stationary wings **642** that generate lift based on the wing shape and the vehicle's forward airspeed. This wing configuration is different from a rotorcraft's configuration, which produces lift through rotating rotors about a fixed mast, and an ornithopter's configuration, which produces lift by flapping wings.

FIG. 6C depicts some common structures used in a fixed-wing aircraft **640**. In particular, fixed-wing aircraft **640** includes a fuselage **644**, two horizontal wings **642** with an airfoil-shaped cross section to produce an aerodynamic force, a vertical stabilizer **646** (or fin) to stabilize the plane's yaw (turn left or right), a horizontal stabilizer **648** (also referred to as an elevator or tailplane) to stabilize pitch (tilt up or down), landing gear **650**, and a propulsion unit **652**, which can include a motor, shaft, and propeller.

FIG. 6D shows an example of an aircraft **660** with a propeller in a pusher configuration. The term "pusher" refers to the fact that the propulsion unit **668** is mounted at the back of the aircraft and "pushes" the vehicle forward, in contrast to the propulsion unit being mounted at the front of the aircraft. Similar to the description provided for FIG. 6C, FIG. 6D depicts common structures used in the pusher plane: a fuselage **662**, two horizontal wings **664**, vertical stabilizers **666**, and a propulsion unit **668**, which can include a motor, shaft, and propeller.

UAVs can be launched in various ways, using various types of launch systems (which may also be referred to as deployment systems). A very simple way to launch a UAV is a hand launch. To perform a hand launch, a user holds a portion of the aircraft, preferably away from the spinning rotors, and throws the aircraft into the air while contemporaneously throttling the propulsion unit to generate lift.

Rather than using a hand launch procedure in which the person launching the vehicle is exposed to risk from the quickly spinning propellers, a stationary or mobile launch station can be utilized. For instance, a launch system can include supports, angled and inclined rails, and a backstop. The aircraft begins the launch system stationary on the angled and inclined rails and launches by sufficiently increasing the speed of the propeller to generate forward airspeed along the incline of the launch system. By the end of the angled and inclined rails, the aircraft can have sufficient airspeed to generate lift. As another example, a launch system may include a rail gun or cannon, either of which may launch a UAV by thrusting the UAV into flight. A launch system of this type may launch a UAV quickly and/or may launch a UAV far towards the UAV's destination. Other types of launch systems may also be utilized.

In some cases, there may be no separate launch system for a UAV, as a UAV may be configured to launch itself. For example, a "tail sitter" UAV typically has fixed wings to provide lift and allow the UAV to glide, but also is configured to take off and land vertically on its own. Other examples of self-launching UAVs are also possible.

In a further aspect, various other types of unmanned vehicles may be utilized to provide remote medical support. Such vehicles may include, for example, unmanned ground vehicles (UGVs), unmanned space vehicles (USVs), and/or unmanned underwater vehicles (UUVs). A UGV may be a vehicle which is capable of sensing its own environment and navigating surface-based terrain without input from a driver. Examples of UGVs include watercraft, cars, trucks, buggies, motorcycles, treaded vehicles, and retrieval duck decoys, among others. A UUV is a vehicle that is capable of sensing

32

its own environment and navigating underwater on its own, such as a submersible vehicle. Other types of unmanned vehicles are possible as well.

## VII. EXAMPLE COMPONENTS OF A UAV

FIG. 7 is a simplified block diagram illustrating components of a UAV **700**, according to an example embodiment. UAV **700** may take the form of or be similar in form to one of the UAVs **600**, **620**, **640**, and **660** shown in FIGS. 6A-6D. However, UAV **700** may also take other forms.

UAV **700** may include various types of sensors, and may include a computing system configured to provide the functionality described herein. In the illustrated embodiment, the sensors of UAV **700** include an inertial measurement unit (IMU) **702**, ultrasonic sensor(s) **704**, GPS **706**, imaging system(s) **708**, among other possible sensors and sensing systems. The UAV **700** also includes a communication system **710**, a payload delivery system **720**, and propulsion system(s) **722**.

The UAV **700** can include one or more processors **718**. The processor(s) **718** may include a general-purpose processor or a special purpose processor (e.g., digital signal processors, application specific integrated circuits, etc.). The one or more processors **718** can be configured to execute computer-readable program instructions **714** that are stored in the data storage **712** and are executable to provide the functionality of a UAV described herein.

The data storage **712** may include or take the form of one or more computer-readable storage media that can be read or accessed by at least one processor **718**. The one or more computer-readable storage media can include volatile and/or non-volatile storage components, such as optical, magnetic, organic or other memory or disc storage, which can be integrated in whole or in part with at least one of the one or more processors **718**. In some embodiments, the data storage **712** can be implemented using a single physical device (e.g., one optical, magnetic, organic or other memory or disc storage unit), while in other embodiments, the data storage **712** can be implemented using two or more physical devices.

As noted, the data storage **712** can include computer-readable program instructions **714** and perhaps additional data, such as diagnostic data of the UAV **700**. The program instructions **714** may be configured to cause the UAV **700** to perform or facilitate some or all of the UAV functionality described herein. For instance, in the illustrated embodiment, program instructions **714** include a navigation module **715** and an automated delivery module **716**. The navigation module **715** can be a set of program instructions that, when executed by the processor(s) **718**, generate flight commands to operate the propulsion system(s) **722** so as to cause the UAV **700** to navigate to a particular location and/or along a particular flight path. The delivery module **716** can be a set of program instructions that, when executed by the processor(s) **718**, operate the payload delivery system **720** to lower a payload to the ground and release the payload. The delivery module **716** may also function to cause the UAV **700** to receive communication(s) from a remote operator indicative of a particular target location at which to deliver the payload and/or an authorization to initiate delivery and/or retraction of the payload delivery system **720**. Other functions are also possible, including functions of the UAVs and payload delivery systems described above in connection with FIGS. 1-5.

### A. Sensors

In an illustrative embodiment, IMU **702** may include both an accelerometer and a gyroscope, which may be used together to determine the orientation, position, and/or eleva-



tion of the UAV 700. In particular, the accelerometer can measure the orientation of the UAV 700 with respect to earth, while the gyroscope measures the rate of rotation around an axis. IMUs are commercially available in low-cost, low-power packages. For instance, an IMU 702 may take the form of or include a miniaturized MicroElectroMechanical System (MEMS) or a NanoElectroMechanical System (NEMS). Other types of IMUs may also be utilized.

An IMU 702 may include other sensors, in addition to accelerometers and gyroscopes, which may help to better determine position and/or help to increase autonomy of the UAV 700. Two examples of such sensors are magnetometers and pressure sensors. Other examples are also possible. (Note that a UAV could also include such additional sensors as separate components from an IMU.)

While an accelerometer and gyroscope may be effective at determining the orientation of the UAV 700, slight errors in measurement may compound over time and result in a more significant error. However, an example UAV 700 may be able to mitigate or reduce such errors by using a magnetometer to measure direction. One example of a magnetometer is a low-power, digital 3-axis magnetometer, which can be used to realize an orientation independent electronic compass for accurate heading information based on the Earth's magnetic field. However, other types of magnetometers may be utilized as well.

UAV 700 may also include a pressure sensor or barometer, which can be used to determine the altitude of the UAV 700. Alternatively, other sensors, such as sonic altimeters or radar altimeters, can be used to provide an indication of altitude, which may help to improve the accuracy of and/or prevent drift of an IMU.

In a further aspect, UAV 700 may include one or more sensors that allow the UAV to sense objects in the environment. For instance, in the illustrated embodiment, UAV 700 includes ultrasonic sensor(s) 704. Ultrasonic sensor(s) 704 can determine the distance to an object by generating sound waves and determining the time interval between transmission of the wave and receiving the corresponding echo off an object. A typical application of an ultrasonic sensor for unmanned vehicles or IMUs is low-level altitude control and obstacle avoidance. An ultrasonic sensor can also be used for vehicles that need to hover at a certain height or need to be capable of detecting obstacles. Other systems can be used to determine, sense the presence of, and/or determine the distance to nearby objects, such as a light detection and ranging (LIDAR) system, laser detection and ranging (LADAR) system, and/or an infrared or forward-looking infrared (FLIR) system, among other possibilities.

UAV 700 also includes a GPS receiver 706. The GPS receiver 706 may be configured to provide data that is typical of well-known GPS systems, such as the GPS coordinates of the UAV 700. Such GPS data may be utilized by the UAV 700 for various functions. For example, the UAV 700 may use its GPS receiver 706 to help navigate to a target GPS location. In some scenarios a target GPS location may be based in part on a database that associates GPS coordinates with street addresses or may be based in part on GPS coordinates obtained from a mobile device. Other examples are also possible.

UAV 700 may also include one or more imaging system(s) 708. For example, one or more still and/or video cameras may be utilized by a UAV 700 to capture image data from the UAV's environment. As a specific example, charge-coupled device (CCD) cameras or complementary metal-oxide-semiconductor (CMOS) cameras can be used with unmanned vehicles. Such imaging sensor(s) 708 have numerous pos-

sible applications, such as obstacle avoidance, localization techniques, ground tracking for more accurate navigation (e.g., by applying optical flow techniques to images), video feedback, and/or image recognition and processing, among other possibilities.

In a further aspect, UAV 700 may use its one or more imaging system 708 to help in determining location. For example, UAV 700 may capture imagery of its environment and compare it to what it expects to see in its environment given current estimated position (e.g., its current GPS coordinates), and refine its estimate of its position based on this comparison.

In a further aspect, UAV 700 may include one or more microphones. Such microphones may be configured to capture sound from the UAV's environment. Other environmental sensors are also possible.

#### B. Navigation and Location Determination

The navigation module 715 may provide functionality that allows the UAV 700 to, e.g., move about in its environment and reach a desired location. To do so, the navigation module 715 may control the altitude and/or direction of flight by controlling the mechanical features of the UAV that affect flight (e.g., rotors 602 of UAV 600).

In order to navigate the UAV 700 to a target location, a navigation module 715 may implement various navigation techniques, such as map-based navigation and localization-based navigation, for instance. With map-based navigation, the UAV 700 may be provided with a map of its environment, which may then be used to navigate to a particular location on the map. With localization-based navigation, the UAV 700 may be capable of navigating in an unknown environment using localization. Localization-based navigation may involve a UAV 700 building its own map of its environment and calculating its position within the map and/or the position of objects in the environment. For example, as a UAV 700 moves throughout its environment, the UAV 700 may continuously use localization to update its map of the environment. This continuous mapping process may be referred to as simultaneous localization and mapping (SLAM). Other navigation techniques may also be utilized.

In some embodiments, the navigation module 715 may navigate using a technique that relies on waypoints. In particular, waypoints are sets of coordinates that identify points in physical space. For instance, an air-navigation waypoint may be defined by a certain latitude, longitude, and altitude. Accordingly, navigation module 715 may cause UAV 700 to move from waypoint to waypoint, in order to ultimately travel to a final destination (e.g., a final waypoint in a sequence of waypoints).

In a further aspect, navigation module 715 and/or other components and systems of UAV 700 may be configured for "localization" to more precisely navigate to the scene of a medical situation or other target location. More specifically, it may be desirable in certain situations for a UAV to be close to the person in need of medical support (e.g., within reach of the person), so as to properly provide medical support to the person. To this end, the UAV 700 may use a two-tiered approach in which it uses a more-general location-determination technique to navigate to a target area, and then use a more-refined location-determination technique to identify and/or navigate to the target location within the target area.

In an alternative arrangement, a navigation module may be implemented at a remote computing device (e.g., a computing device associated with a remote operator), which communicates wirelessly with the UAV 700. The remote computing device may receive data indicating the operational state of the UAV 700, sensor data from the UAV 700 that allows it to

assess the environmental conditions being experienced by the UAV 700, and/or location information for the UAV 700. Provided with such information, the remote computing device may determine latitudinal and/or directional adjustments that should be made by the UAV 700 and/or may determine how the UAV should adjust its mechanical features (e.g., rotors 602 of UAV 600) in order to effectuate such movements. The remote computing system may then communicate such adjustments to the UAV 700 so it can move in the determined manner. Such commands to the electromechanical propulsion systems 722 of the UAV 700 may be referred to herein as flight-control commands, whether generated by a remote computing system or by the navigation module 715 on the UAV 700.

#### C. Payload Delivery

The payload delivery module 716 may provide functionality that allows the UAV 700 to autonomously or semi-autonomously lower a payload to the ground and release the payload, thereby effecting delivery of the payload on the ground. In practice, the payload delivery module 716 may be a set of program instructions that generates commands to electromechanical components and/or control systems of the payload delivery system 720 (e.g., the payload delivery system 110 of UAV 100).

The payload delivery system 720 may include aspects that selectively secure and release a payload (e.g., the payload-release device 106), and that selectively lower the payload to the ground (e.g., the tether-deployment mechanism 104 and tether 102). In some cases, the payload may be lowered to the ground using a retractable payload-release device that is secured to the payload during descent and that includes sensors to facilitate monitoring of the payload as it descends from the UAV 700. The payload-release device may, for example, communicate information from an inertial measurement unit and/or altimeter via a wireless connection with the UAV 700. Data from such sensors on the payload-release device can then be used by the payload delivery module 716 to determine when the payload and/or the payload-release device have reached the ground (e.g., based on accelerometer data indicating impact with the ground). Data from the sensors can also be used to determine whether the payload, payload-release device, and/or tether may have become stuck in an obstacle such as a tree or fence, or otherwise interfered with by a vehicle or perhaps a pedestrian.

In addition, the payload delivery module 716 can function to cause the payload-release assembly to ascend/descend at rates selected to encourage an intuitive, safe, and efficient interaction between the payload delivery system and people on the ground, as described above. Additionally or alternatively, the payload delivery module 716 can cause a bystander communication module to generate cues for perception by people on the ground during the delivery operation as described above. Other functionality of the payload delivery system 720 (and the payload delivery module 716) may include functions of the payload delivery systems described above in connection with FIGS. 1-5.

#### D. Communication Systems

In a further aspect, UAV 700 includes one or more communication systems 710. The communications systems 710 may include one or more wireless interfaces and/or one or more wireline interfaces, which allow UAV 700 to communicate via one or more networks. Such wireless interfaces may provide for communication under one or more wireless communication protocols, such as Bluetooth, WiFi (e.g., an IEEE 802.11 protocol), Long-Term Evolution (LTE), WiMAX (e.g., an IEEE 802.16 standard), a radio-frequency ID (RFID) protocol, near-field communication (NFC), and/or

other wireless communication protocols. Such wireline interfaces may include an Ethernet interface, a Universal Serial Bus (USB) interface, or similar interface to communicate via a wire, a twisted pair of wires, a coaxial cable, an optical link, a fiber-optic link, or other physical connection to a wireline network.

In an example embodiment, a UAV 700 may include communication systems 710 that allow for both short-range communication and long-range communication. For example, the UAV 700 may be configured for short-range communications using Bluetooth and for long-range communications under a CDMA protocol. In such an embodiment, the UAV 700 may be configured to function as a "hot spot;" or in other words, as a gateway or proxy between a remote support device and one or more data networks, such as cellular network and/or the Internet. Configured as such, the UAV 700 may facilitate data communications that the remote support device would otherwise be unable to perform by itself.

For example, UAV 700 may provide a WiFi connection to a remote device, and serve as a proxy or gateway to a cellular service provider's data network, which the UAV 700 might connect to under an LTE or a 3G protocol, for instance. The UAV 700 could also serve as a proxy or gateway to a high-altitude balloon network, a satellite network, or a combination of these networks, among others, which a remote device might not be able to otherwise access.

#### E. Power Systems

In a further aspect, UAV 700 may include power system(s) 724. A power system 724 may include one or more batteries for providing power to the UAV 700. In one example, the one or more batteries may be rechargeable and each battery may be recharged via a wired connection between the battery and a power supply and/or via a wireless charging system, such as an inductive charging system that applies an external time-varying magnetic field to an internal battery.

#### F. Payloads

UAV 700 may employ various systems and configurations in order to transport items. In the illustrated embodiment, a payload may serve as a compartment that can hold one or more items, such that a UAV 700 can deliver the one or more items to a target delivery location. For example, as shown in FIG. 6A, the UAV 600 can include a compartment 608, in which an item or items may be transported. As another example, the UAV 700 can include a pick-and-place mechanism, which can pick up and hold the item while the UAV 700 is in flight, and then release the item during or after the UAV's descent. As yet another example, the UAV 700 could include an air-bag drop system, a parachute drop system, and/or a winch system that is operable to drop or lower an item or items to a delivery location. Other examples are also possible. In some implementations, the payload of the UAV 700 may include or take the form of a "package" designed to transport medical-support items to a target delivery location. For example, a medical-support UAV may include a package with one or more items for medical support in the particular medical situation, and/or one or more medical-support modules that are designed to provide medical support in the particular medical situation. In some cases, a UAV 700 may include a package that is designed for a particular medical situation such as choking, cardiac arrest, shock, asthma, drowning, etc. In other cases, a UAV 700 may include a package that is designed for a number of different medical situations, which may be associated in some way.

Such medical support items may aid in diagnosing and/or treating a person who needs medical assistance, or may serve other purposes. Example of medical-support items include, but are not limited to: (a) medicines, (b) diagnostic devices,

such as a pulse oximeter, blood pressure sensor, or EKG sensor, (c) treatment devices, such as an EpiPen, a first aid kit, or various kinds of defibrillators (e.g., an automated external defibrillator (AED)), and/or (d) remote support devices, such as a mobile phone or a head-mountable device (HMD), among other possibilities. Note that some items that are electronic may include one or more batteries to provide power to the item. These batteries may be rechargeable and may be recharged using one or more wired or wireless charging systems. In addition or on the alternative, an item may be integrated with one or more batteries in the power system **724** for power.

In some embodiments, UAV **700** could include an integrated system or device for administering or assisting in the administration of medical care (e.g., a system or device having one or more components that are built in to the structure of the UAV itself). For example, as noted above, a UAV could include an oxygen-therapy system. In an example configuration, an oxygen-therapy system might include a mask that is connected via tubing to an on-board oxygen source. Configured as such, the UAV could release the oxygen mask when it reaches a person in need of oxygen (e.g., at a fire scene).

As another example of a UAV with an integrated medical-support device, UAV **700** might function as a mobile defibrillator. Specifically, rather than carry a stand-alone defibrillator that can then be removed from the UAV for use, the UAV itself may function as a defibrillator.

#### G. Service Modules

As noted above, UAV **700** may include one or more service modules. The one or more service modules may include software, firmware, and/or hardware that may help to provide or assist in the provision of the UAV-related services. In some examples, the one or more service modules described herein may be implemented, at least in part, by the program instructions **714** configured to be executed by the processor(s) **718**.

Configured as such, a UAV **700** may provide various types of service. For instance, the UAV **700** may have stored information that can be provided to a person or persons at the target location, in order to assist the person or persons in various ways. For example, the UAV **700** may include a video or audio file with instructions for performing some task, which the UAV **700** can play out to a person at the target location. As another example, the UAV **700** may include an interactive program to assist a person at the target location in performing some task. For instance, the UAV **700** may include an application that analyzes the person's speech to detect questions related to the medical situation and/or that provides a text-based interface via which the person can ask such questions, and then determines and provides answers to such questions.

In some embodiments, UAV **700** may facilitate communication between a layperson and/or medical personnel at the scene and medical personnel at a remote location. As an example, a service module may provide a user interface via which a person at the scene can use a communication system **710** of the UAV to communicate with an emergency medical technician at a remote location. As another example, the UAV **700** can unlock certain capabilities of a remote device, such as a mobile phone, which is near the UAV **700** at the scene of a medical situation. Such capabilities may be inaccessible to a user of the remote device, unless the remote device is within a certain distance from the UAV **700** such that the UAV **700** can unlock the capabilities. For example, the UAV **700** may send the remote device a security key that allows the remote device to establish a secure connection to communicate with medical personnel at a remote location. Other examples are also possible.

#### VIII. EXAMPLE UAV SYSTEMS

UAV systems may be implemented in order to provide various services. In particular, UAVs may be provided at a number of different launch sites, which may be in communication with regional and/or central control systems. Such a distributed UAV system may allow UAVs to be quickly deployed to provide services across a large geographic area (e.g., that is much larger than the flight range of any single UAV). For example, UAVs capable of carrying payloads may be distributed at a number of launch sites across a large geographic area (possibly even throughout an entire country, or even worldwide), in order to deliver various items to locations throughout the geographic area. As another example, a distributed UAV system may be provided in order to provide remote medical support, via UAVs. FIG. **8** is a simplified block diagram illustrating a distributed UAV system **800**, according to an example embodiment.

In an example UAV system **800**, an access system **802** may allow for interaction with, control of, and/or utilization of a network of UAVs **804**. In some embodiments, an access system **802** may be a computing system that allows for human-controlled dispatch of UAVs **804**. As such, the control system may include or otherwise provide a user interface (UI) **803** via which a user can access and/or control UAVs **804**. In some embodiments, dispatch of UAVs **804** may additionally or alternatively be accomplished via one or more automated processes. The access system **802** and associated UI **803** that allow for human-controlled dispatch may be implemented, for example, using a remote terminal for supervisory control that provides information to a human operator (e.g., a video stream from one of the UAVs **804**), and receives an input from the remote operator to indicate an action to be performed by the UAV **804**.

Further, the access system **802** may provide for remote operation of a UAV. For instance, an access system **802** may allow an operator to control the flight of a UAV **804** via user interface **803**. As a specific example, an operator may use an access system to dispatch a UAV **804** to deliver a package to a target location. The UAV **804** may then autonomously navigate to the general area of the target location. At this point, the operator may use the access system **802** to take over control of the UAV **804**, and navigate the UAV to the target location (e.g., to a particular person to whom a payload is being sent). Other examples of remote operation of the UAV **804** are also possible.

The UAVs **804** may take various forms. For example, each UAV **804** may be a UAV such as those illustrated in FIGS. **6A-6D**. However, UAV system **800** may also utilize other types of UAVs without departing from the scope of the present disclosure. In some implementations, all UAVs **804** may be of the same or a similar configuration. However, in other implementations, UAVs **804** may include a number of different types of UAVs. For instance, UAVs **804** may include a number of types of UAVs, with each type of UAV being configured for a different type or types of medical support.

A remote device **806** may take various forms. Generally, a remote device **806** may be any device via which a direct or indirect request to dispatch UAV **804** can be made. (Note that an indirect request may involve any communication that may be responded to by dispatching a UAV; e.g., requesting a payload delivery). In an example embodiment, a remote device **806** may be a mobile phone, tablet computer, laptop computer, personal computer, or any network-connected computing device. Further, in some instances, remote device **806** may not be a computing device. As an example, a standard telephone, which allows for communication via plain

old telephone service (POTS), may serve as a remote device **806**. Other types of remote devices are also possible.

Further, a remote device **806** may be configured to communicate with access system **802** via one or more types of communication network(s). For example, a remote device **806** could communicate with access system **802** (or via a human operator of the access system) by placing a phone call over a POTS network, a cellular network, and/or a data network such as the Internet. Other types of networks may also be utilized.

In some embodiments, a remote device **806** may be configured to allow a user to request delivery of one or more items to a desired location. For example, a user could request UAV delivery of a payload to their home via their mobile phone, tablet, or laptop. As another example, a user could request dynamic delivery to whatever location they are at the time of delivery. To provide such dynamic delivery, the UAV system **800** may receive location information (e.g., GPS coordinates, etc.) from the user's mobile phone, or any other device on the user's person, such that the UAV **804** can navigate to the user's location (as indicated by their mobile phone).

In an example arrangement, central dispatch system **808** may be a server or group of servers, which is configured to receive dispatch messages requests and/or dispatch instructions from an access system **802**. Such dispatch messages may request or instruct the central dispatch system **808** to coordinate the deployment of UAVs to various target locations. A central dispatch system **808** may be further configured to route such requests or instructions to local dispatch systems **810**. To provide such functionality, central dispatch system **808** may communicate with access system **802** via a data network, such as the Internet or a private network that is established for communications between access systems and automated dispatch systems.

In the illustrated configuration, central dispatch system **808** may be configured to coordinate the dispatch of UAVs **804** from a number of different local dispatch systems **810**. As such, central dispatch system **808** may keep track of which UAVs **804** are located at which local dispatch systems **810**, which UAVs **804** are currently available for deployment, and/or which services or operations each of the UAVs **804** is configured for (in the event that a UAV fleet includes multiple types of UAVs configured for different services and/or operations). Additionally or alternatively, each local dispatch system **810** may be configured to track which of its associated UAVs **804** are currently available for deployment and/or which services or operations each of its associated UAVs is configured for.

In some cases, when central dispatch system **808** receives a request for UAV-related service from an access system **802**, central dispatch system **808** may select a specific UAV **804** to dispatch. The central dispatch system **808** may accordingly instruct the local dispatch system **810** that is associated with the selected UAV to dispatch the selected UAV. The local dispatch system **810** may then operate its associated deployment system **812** to launch the selected UAV. In other cases, a central dispatch system **808** may forward a request for a UAV-related service to a local dispatch system **810** that is near the location where the support is requested, and leave the selection of a particular UAV **804** to the local dispatch system **810**.

In an example configuration, a local dispatch system **810** may be implemented in a computing system at the same location as the deployment system or systems **812** that it controls. For example, in some embodiments, a local dispatch system **810** could be implemented by a computing system at a building where the deployment systems **812** and UAVs **804**

that are associated with the particular local dispatch system **810** are also located. In other embodiments, a local dispatch system **810** could be implemented at a location that is remote to its associated deployment systems **812** and UAVs **804**.

Numerous variations on and alternatives to the illustrated configuration of UAV system **800** are possible. For example, in some embodiments, a user of a remote device **806** could request medical support directly from a central dispatch system **808**. To do so, an application may be implemented on a remote device **806** that allows the user to provide information regarding a requested service, and generate and send a data message to request that the UAV system provide the service. In such an embodiment, central dispatch system **808** may include automated functionality to handle requests that are generated by such an application, evaluate such requests, and, if appropriate, coordinate with an appropriate local dispatch system **810** to deploy a UAV.

Further, in some implementations, some or all of the functionality that is attributed herein to central dispatch system **808**, local dispatch system(s) **810**, access system **802**, and/or deployment system(s) **812** could be combined in a single system, implemented in a more complex system, and/or redistributed among central dispatch system **808**, local dispatch system(s) **810**, access system **802**, and/or deployment system(s) **812** in various ways.

Yet further, while each local dispatch system **810** is shown as having two associated deployment systems, a given local dispatch system **810** may have more or less associated deployment systems. Similarly, while central dispatch system **808** is shown as being in communication with two local dispatch systems **810**, a central dispatch system may be in communication with more or less local dispatch systems **810**.

In a further aspect, a deployment system **812** may take various forms. In general, a deployment system may take the form of or include a system for physically launching a UAV **804**. Such a launch system may include features that allow for a human-assisted UAV launch and/or features that provide for an automated UAV launch. Further, a deployment system **812** may be configured to launch one particular UAV **804**, or to launch multiple UAVs **804**.

A deployment system **812** may further be configured to provide additional functions, including for example, diagnostic-related functions such as verifying system functionality of the UAV, verifying functionality of devices that are housed within a UAV (e.g., such as a defibrillator, a mobile phone, or an HMD), and/or maintaining devices or other items that are housed in the UAV (e.g., by charging a defibrillator, mobile phone, or HMD, or by checking that medicine has not expired).

In some embodiments, the deployment systems **812** and their corresponding UAVs **804** (and possibly associated local dispatch systems **810**) may be strategically distributed throughout an area such as a city. For example, deployment systems **812** may be located on the roofs of certain municipal buildings, such as fire stations, which can thus serve as the dispatch locations for UAVs **804**. Fire stations may function well for dispatch of emergency response UAVs (e.g., UAVs used to deliver emergency medical supplies, relief items, or interactive equipment to assist people in responding to an emergency situation). Fire stations tend to be distributed well with respect to population density, their roofs tend to be flat, and the use of firehouse roofs as leased spaces for dispatch of emergency response UAVs could further the public good. However, deployment systems **812** (and possibly the local dispatch systems **810**) may be distributed in other ways, depending upon the particular implementation. As an additional example, kiosks that allow users to transport packages

41

via UAVs may be installed in various locations. Such kiosks may include UAV launch systems, and may allow a user to provide their package for loading onto a UAV and pay for UAV shipping services, among other possibilities. Other examples are also possible.

In a further aspect, a UAV system **800** may include or have access to a user-account database **814**. The user-account database **814** may include data for a number of user-accounts, which are each associated with one or more persons. For a given user-account, the user-account database **814** may include data related to or useful in providing UAV-related services. Typically, the user data associated with each user-account is optionally provided by an associated user and/or is collected with the associated user's permission.

Further, in some embodiments, a person may have to register for a user-account with the UAV system **800** in order to use or be provided with UAV-related services by the UAVs **804** of UAV system **800**. As such, the user-account database **814** may include authorization information for a given user-account (e.g., a user-name and password), and/or other information that may be used to authorize access to a user-account.

In some embodiments, a person may associate one or more of their devices with their user-account, such that they can be provided with access to the services of UAV system **800**. For example, when a person uses an associated mobile phone, e.g., to place a call to an operator of access system **802** or to send a message requesting a UAV-related service to a dispatch system, the phone may be identified via a unique device identification number, and the call or message may then be attributed to the associated user-account. Other examples are also possible.

In some examples, an individual user or a group of users may create a data-based "user-account," which may also be referred to simply as an "account." A user-account for a particular user or user group may include data related to the particular user or user group, which the user or user group has opted to provide for the user-account. As such, a particular user's account may, in a sense, be a data-based representation of that particular user. A user may create an account for various applications, web sites, and/or online services, for instance. Examples of user accounts include e-mail accounts, social network accounts, online financial accounts, accounts with service providers, among other possibilities. Further, in some cases, a user may have a single user-account that provides as a data-based representation of the user for multiple services, websites, applications, etc. For instance, a user could opt to use their e-mail account or social network account as a common login for various online services and applications, which are provided by a number of different entities. Further, a user of a computing device, such as a mobile phone, laptop computer, or wearable computing device, may associate their user-account with the computing device itself, such that while the user is operating the computing device, their account will be associated with applications that are provided on the computing device.

In situations in which the systems discussed here collect personal information about users, or may make use of personal information, the users may be provided with an opportunity to control whether programs or features collect user information (e.g., information about a user's social network, social actions or activities, profession, a user's preferences, or a user's current location), or to control whether and/or how to receive content from the content server that may be more relevant to the user. In addition, certain data may be treated in one or more ways before it is stored or used, so that personally identifiable information is removed. For example, a user's identity may be treated so that no personally identifiable

42

information can be determined for the user, or a user's geographic location may be generalized where location information is obtained (such as to a city, ZIP code, or state level), so that a particular location of a user cannot be determined.

Thus, the user may have control over how information is collected about the user and used by a content server.

## IX. CONCLUSION

Where example embodiments involve information related to a person or a device of a person, the embodiments should be understood to include privacy controls. Such privacy controls include, at least, anonymization of device identifiers, transparency and user controls, including functionality that would enable users to modify or delete information relating to the user's use of a product.

The particular arrangements shown in the Figures should not be viewed as limiting. It should be understood that other embodiments may include more or less of each element shown in a given Figure. Further, some of the illustrated elements may be combined or omitted. Yet further, an exemplary embodiment may include elements that are not illustrated in the Figures.

Additionally, while various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are contemplated herein.

What is claimed is:

1. A delivery device comprising:

a housing including: (i) a channel arranged to receive a payload, and (ii) a tether attachment feature configured to couple the housing to a tether;

a retaining rod coupled to the housing, wherein the retaining rod is configured to be positioned in: (i) a first position in which a portion of the retaining rod engages the payload when the payload is inserted in the channel, and (ii) a second position in which the retaining rod does not engage the payload;

a non-transitory computer readable medium comprising program instructions stored thereon; and

a processor operable to execute the program instructions to:

(i) during a delivery operation in which the delivery device is lowered to a ground via the tether, position the retaining rod in the first position to secure the payload to the delivery device;

(ii) determine that the delivery device is at or near the ground; and

(iii) in response to determining that the delivery device is at or near the ground, move the retaining rod from the first position to the second position such that the payload is released from the delivery device.

2. The delivery device of claim 1, further comprising an actuator mechanically coupled to the retaining rod, and wherein the movement of the retaining rod from the first position to the second position comprises application of force to the retaining rod so as to move the retaining rod.

43

3. The delivery device of claim 1, wherein the determination that the delivery device is at or near the ground comprises:

- (i) determining that the delivery device is within a threshold distance of the ground,
- (ii) in response to determining that the delivery device is within the threshold distance of the ground, determining that an instantaneous acceleration of the delivery device exceeds a first threshold; and
- (iii) subsequent to determining that the instantaneous acceleration of the delivery device exceeds the threshold, determining that the instantaneous acceleration of the delivery device is less than or equal to a second threshold, wherein the second threshold is lower than the first threshold.

4. The delivery device of claim 3, further comprising one or more sensors arranged on or within the delivery device, wherein the one or more sensors are configured to generate sensor data indicative of a location of the delivery device, and wherein the processor is operable to execute the program instructions to:

receive sensor data from the one or more sensors, and base one or more of the determination that the delivery device is within the threshold distance of the ground, the determination that the instantaneous acceleration of the delivery device exceeds the first threshold, and the determination that the instantaneous acceleration of the delivery device is less than the second threshold, on the received sensor data.

5. The delivery device of claim 4, wherein the one or more sensors comprise at least one of an accelerometer or an altimeter.

6. The delivery device of claim 3, further comprising a physical communication interface configured to receive information from an unmanned aerial vehicle (UAV) coupled to the delivery device via the tether, and wherein the processor is configured to execute the program instructions to use the received information as at least a partial basis for one or more of the determination that the delivery device is within the threshold distance of the ground, the determination that the instantaneous acceleration of the delivery device exceeds the first threshold, and the determination that the instantaneous acceleration of the delivery device is less than the second threshold.

7. The delivery device of claim 1, wherein the retaining rod comprises a hook mounted to the housing so as to rotate about an axis of rotation, and wherein the retaining rod moving from the first position to the second position comprises the hook rotating about the axis of rotation.

8. The delivery device of claim 1, wherein the retaining rod is configured such that, while in the first position, at least a portion of the retaining rod intersects respective planes defined by opposing sidewalls of the channel, and while in the disengaged position, the retaining rod does not intersect at least one of the respective planes.

9. The delivery device of claim 8, wherein the retaining rod is configured such that, when in the first position, the retaining rod is situated within the channel of the housing.

10. The delivery device of claim 8, wherein the retaining rod is configured such that, when in the first position, at least a portion of the retaining rod is situated along an exterior surface of the housing adjacent the channel.

11. The delivery device of claim 1, wherein the payload comprises a tab having a substrate with an aperture formed therein, wherein the aperture is bounded by an interior rim, wherein the tab is configured such that, while the tab is inserted into the channel, the aperture is aligned so as to

44

receive the retaining rod while the retaining rod is in the first position so as to secure the tab to the delivery device via contact between the retaining rod and the interior rim.

12. A method comprising:

while a delivery device is being lowered from an unmanned aerial vehicle (UAV) via a tether coupled to the delivery device and the UAV, receiving sensor data that is generated by one or more sensors arranged on or within the delivery device, wherein the sensor data is indicative of a location of the delivery device;

determining, by a processor, based at least in part on the received sensor data, that the delivery device is within a threshold distance of a ground;

in response to determining that the delivery device is within the threshold distance of the ground, determining, based at least in part on the received sensor data, that an instantaneous acceleration of the delivery device exceeds a first threshold; and

subsequent to determining that the instantaneous acceleration of the delivery device exceeds the first threshold, determining, based at least in part on the received sensor data, that the instantaneous acceleration of the delivery device is less than a second threshold, wherein the second threshold is less than the first threshold; and

in response to determining that the instantaneous acceleration of the delivery device is less than the second threshold, releasing a payload from the delivery device.

13. The method of claim 12, wherein the one or more sensors comprise at least one of an accelerometer or an altimeter.

14. The method of claim 12, further comprising positioning a retaining rod in a first position while the delivery device is being lowered from the UAV such that the payload is secured to the delivery device, wherein the delivery device comprises a housing and the retaining rod is coupled to the housing, wherein the housing has a channel configured to receive the payload, wherein the retaining rod is configured to be positioned in: (i) the first position in which a portion of the retaining rod engages the payload via the channel, and (ii) a second position in which the retaining rod does not engage the payload;

wherein releasing the payload from the delivery device comprises moving the retaining rod from the first position to the second position such that the payload is released from the delivery device.

15. The method of claim 14, wherein the delivery device further comprises an actuator mechanically coupled to the retaining rod, and wherein moving the retaining rod from the first position to the second position comprises causing the actuator to apply force to the retaining rod such that the retaining rod moves from the first position to the second position.

16. The method of claim 14, wherein the retaining rod is configured such that, when in the first position, at least a portion of the retaining rod intersects respective planes defined by opposing sidewalls of the channel, and, when in the second position, the retaining rod does not intersect at least one of the respective planes.

17. A system comprising:

a retractable delivery system comprising:

- (i) a delivery device releasably coupled to a payload;
- (ii) one or more sensors arranged on or within the delivery device, wherein the one or more sensors are configured to generate sensor data indicative of a location of the delivery device;
- (iii) a tether coupled to an unmanned aerial vehicle (UAV) and the delivery device; and

45

- (iv) a retraction system coupled to the tether and operable to lower the delivery device from the UAV;
- a non-transitory computer readable medium comprising program instructions stored thereon; and
- a processor operable to execute the program instructions to:
  - (i) while the UAV hovers over a delivery location, use the retractable delivery system to initiate delivery, wherein initiating delivery comprises, while the delivery device is secured to the payload, lowering the delivery device from the UAV such that the payload descends from the UAV;
  - (ii) receive sensor data from the one or more sensors;
  - (iii) determine, based at least in part on the received sensor data, that the delivery device is within a threshold distance of a ground;
  - (iv) in response to determining that the delivery device is within the threshold distance of the ground, determine, based at least in part on the received sensor data, that an instantaneous acceleration of the delivery device exceeds a first threshold; and
  - (v) subsequent to determining that the instantaneous acceleration of the delivery device exceeds the first threshold, determining, based at least in part on the received sensor data, that the instantaneous accelera-

46

tion of the delivery device is less than a second threshold, wherein the second threshold is less than the first threshold; and

- (iv) in response to determining that the instantaneous acceleration of the delivery device is less than a second threshold, cause the retractable delivery system to release the payload from the delivery device.

**18.** The system of claim 17, wherein the delivery device further comprises a physical communication interface configured to receive information from the UAV, and wherein the processor is operable to execute the program instructions to use the received information as at least a partial basis to determine that the delivery device is at or near the ground.

**19.** The system of claim 17, wherein the delivery device comprises a housing and a retaining rod coupled to the housing, wherein the housing has a channel configured to receive a payload, wherein the retaining rod is configured to be positioned in: (i) a first position in which a portion of the retaining rod engages the payload, and (ii) a second position in which the retaining rod does not engage the payload; and

wherein the release of the payload from the delivery device moves the retaining rod from the first position to the second position and such that the payload is released from the delivery device.

\* \* \* \* \*